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MODELING THE EFFECTS OF A TRANSPORTATION SECURITY INCIDENT ON THE COMMERCIAL CONTAINER TRANSPORTATION SYSTEM

by

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September 2009

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We develop a modeling tool to represent freight container flows and the potential changes in cost of those flows inflicted on the U.S. commercial transportation system by a Transportation Security Incident (TSI). Our model includes available data on container movements, origin-destination (O-D) matrices for international container flows entering or leaving the U.S., and development of an attacker-defender model to determine best contingency plans after a TSI. We design a multi-commodity network flow model, representing flows between foreign countries and North American ports, the modal volumes into and out of each port, and volumes between each port and the 84 U.S. Transportation Analysis Zones. Each O-D flow is a commodity with a specified origin and destination. Subject to constraints on total flow volume over the arcs, these commodities flow through the network at minimum cost. The model finds paths through the network for containers to minimize their total transportation costs, and identifies a set of the most-critical infrastructure components of the commercial container transportation system that could be affected by a transportation security incident. This tool can help decision makers identify critical components to improve security and capacity on existing commercial transportation infrastructure in an environment with limited available funding.

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MODELING THE EFFECTS OF A TRANSPORTATION SECURITY INCIDENT ON THE COMMERCIAL TRANSPORTATION SYSTEM

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ABSTRACT

We develop a modeling tool to represent freight container flows and the potential changes in cost of those flows inflicted on the U.S. commercial transportation system by a Transportation Security Incident (TSI). Our model includes available data on container movements, origin-destination (O-D) matrices for international container flows entering or leaving the U.S., and development of an attacker-defender model to determine best contingency plans after a TSI. We design a multi-commodity network flow model, representing flows between foreign countries and North American ports, the modal volumes into and out of each port, and volumes between each port and the 84 U.S. Transportation Analysis Zones. Each O-D flow is a commodity with a specified origin and destination. Subject to constraints on total flow volume over the arcs, these commodities flow through the network at minimum cost. The model finds paths through the network for containers to minimize their total transportation costs, and identifies a set of the most-critical infrastructure components of the commercial container transportation system that could be affected by a transportation security incident. This tool can help decision makers identify critical components to improve security and capacity on existing commercial transportation infrastructure in an environment with limited available funding.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAPA	American Association of Port Authorities
AD	attacker-defender
BEA	Bureau of Economic Analysis
BTS	Bureau of Transportation Statistics
CIKR	critical infrastructure and key resources
DHS	U.S. Department of Homeland Security
EA	Economic Area
ILWU	International Longshoremen and Warehousemen's Union
MARAD	U.S. Maritime Administration
NIPP	National Infrastructure Protection Plan
O-D	origin-destination
PRA	Probabilistic Risk Analysis
RAMCAP	Risk Analysis and Management for Critical Asset Protection
TAZ	transportation analysis zone
TEU	twenty-foot equivalent unit
	As example, one twenty-foot long container equals one TEU while one forty-foot container equals two TEUs
TGS	total ground slots
TSI	Transportation Security Incident
TGS	total ground slots
USGS	United States Geological Survey

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EXECUTIVE SUMMARY

International containerized freight movement is a vital part of the supply chain for many companies, and a critical element of moving consumer goods to points of retail sale within the U.S. Containerized imports also present a clear security concern. The potential for terrorists to ship dirty bombs, chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized and interdiction of such shipments is a primary objective of the Department of Homeland Security. A goal of U.S. Customs and Border Protection is the modeling of supply chain operations and the ability to estimate economic impacts of security-driven delays to material entering the U.S.

We introduce a tool to represent container flows and the potential changes in those flows under a variety of conditions (port disruptions, extensive security-related delays, natural disasters, and so forth). This tool includes available data on container movements, estimation of origin-destination matrices for international container flows entering or leaving the U.S., and development of a network model to represent container movements, in twenty-foot equivalent units (TEUs), both internationally and domestically. This international network model allows flow diversions between U.S. ports because of implementation of security initiatives or port disruptions.

Foreign origins and destinations include 46 countries that, the American Association of Port Authorities (AAPA) says in 2009 account for approximately 96 percent of containers imported by the U.S. through seaports and approximately 93 percent of U.S. seaborne exports. The set of foreign origins and destinations does not include Canada and Mexico. While these two countries are among the U.S.'s largest trading partners, nearly all of the import—export movement is via overland border crossings, not through seaports. The U.S.—Canadian and U.S.—Mexican border crossings are not included in this analysis.

The AAPA also states that more than 90 percent of total containerized traffic entering or leaving the U.S. (measured in TEUs) moves through 14 large ports. These ports are Los Angeles, Long Beach, Oakland, Seattle and Tacoma on the Pacific Coast, New York, Baltimore, Norfolk-Hampton Roads, Charleston, Savannah, Jacksonville, Port Everglades (Ft. Lauderdale) and Miami on the Atlantic Coast, and Houston on the Gulf Coast. The ports of Los Angeles and Long Beach operate separately, but are physically adjacent and for this thesis are modeled as one. Similarly, Seattle and Tacoma are two separate ports, but because they are very close to one another, we group them together. Finally, Miami and Port Everglades are also two separate ports that have been grouped together to represent a South Florida port for the analysis. Thus, we consider 11 U.S. locations as ports, including all 14 of the largest individual facilities.

In addition, Vancouver and Prince Rupert in Canada and Lazaro Cardenas in Mexico are ports on the Pacific Coast that are entry points for containers that subsequently enter the U.S. via land crossings. Thus, 14 ports are represented for U.S. imports and exports. In general, we will refer to these 14 ports as the North American ports and the ports in other parts of the world as foreign ports. Although Vancouver, Prince Rupert, and Lazaro Cardenas are not on U.S. soil, there is little sea traffic from them to U.S. ports, so the focus is on their role as possible points-of-landing for containers that are ultimately destined for U.S. locations.

Inside the U.S., we aggregate shipment origins and destinations into 84 Transportation Analysis Zones (TAZs). Each TAZ represents a collection of counties and a major city in each zone represents each TAZ. Between the ports and the cities representing TAZs, the model includes both rail and truck connections, reflecting the modal choice made by shippers for the domestic part of their supply chain.

The overall model is a network multi-commodity flow model, depicting flows between foreign countries and North American ports, the total volumes handled (import and export) by each port, the modal volumes (truck and rail) into and out of each port, and volumes between each port and each TAZ. The principal reflection of congestion in the model is in the capacity limits for rail connections at the ports. The model finds paths through the network for shipments to minimize their total logistics cost, in travel days, which affects transportation and inventory costs.

We use an Attacker-Defender model to manipulate our transportation network. The model allows the attacker, or leader, to first attack the network, and then the defender, or follower, optimally alters flow of container TEUs on the surviving network. Solving this model for the best response to the worst attack shows how we can identify critical nodes that correspond to the worst-case attack.

Our research reveals that aside from a terrorist attack on the commercial container transportation system the most expensive scenario on that system is when the Pacific Maritime Association Board of Directors locks down the West Coast Ports. The lockout of longshoremen, dockworkers, and marine clerks causes a 43.92% transportation cost increase. We have also found an increase of 14.75% in additional transportation costs when a 7.8 earthquake shakes Southern California and closes the ports of Los Angeles and Long Beach for a period of 14 days. The closure of the ports of Savannah and Charleston, due to a postulated hurricane, will only increase the transportation costs by 0.64%. A reduction in throughput at the Port of Oakland due to increased container security measures would affect overall costs by only 0.53%. In both the Savannah-Charleston and Oakland scenarios, the other regional ports are capable of absorbing the rerouted containers. Finally, we determine the five optimal attacks an intelligent terrorist might employ to maximize the cost on the U.S. economy. Although we include three North American ports not on U.S. soil, all five plans include only domestic U.S. ports. The five optimal target ports for a terrorist are Los Angeles and Long Beach, Oakland, Seattle and Tacoma, Baltimore and New York and New Jersey.

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I. INTRODUCTION

A. OVERVIEW

International containerized freight movement is a vital part of the supply chain for many companies and a critical element of moving consumer goods to points of retail sale within the U.S. Containerized imports also present a clear security concern. The potential for terrorists to ship dirty bombs, chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized. A U.S. Customs and Border Protection's long-term goal is the modeling of supply-chain operations and the ability to estimate economic impacts of security-driven delays to material entering the United States (U.S. Customs and Border Protection, 2009).

Currently, the Department of Homeland Security (DHS) uses the Risk Analysis and Management for Critical Asset Protection (RAMCAP-Plus) program to analyze and manage risk to transportation infrastructure assets and systems. RAMCAP-Plus systematically identifies and ranks critical facility assets that, if attacked by terrorists or exposed to other hazards, could potentially produce significant and adverse impacts. RAMCAP-Plus allows users to conduct vulnerability and risk assessments, starting with the identification of critical assets and culminating in the management of risk for the entire facility (Alion Science and Technology , 2007).

We introduce a modeling tool to represent container flows, and the potential changes in those flows, under a variety of Transportation Security Incidents (port disruptions, extensive security-related delays, natural disasters, and so forth). It includes available data on container movements, origin-destination (O-D) matrices for international container flows entering or leaving the U.S., and development of a network model to represent container movements both internationally and domestically.

Our model includes capacities on total flow through each port, and on each rail link. Road links are uncapacitated in our model, and we do not model time delays due to handling inefficiencies in ports. For our data, the capacities on the rail links are more constraining than port capacities.

Foreign origins and destinations include 46 countries, as shown in Table 1, that account for approximately 96 percent of containers imported by the U.S. through seaports and approximately 93 percent of U.S. seaborne exports (American Association of Port Authorities, 2009). The set of foreign origins and destinations does not include Canada and Mexico. While these two countries are among the U.S.'s largest trading partners, nearly all of the import—export movement is via overland border crossings, not through seaports. The U.S.ï Canadian and U.S.ï Mexican border crossings are not included in this analysis.

Country	Foreign Port Representation	Country	Foreign Port Representation
ARGENTINA	Buenos Aires	ISRAEL	Haifa
AUSTRALIA	Melbourne	ITALY	Gioia Tauro
AUSTRIA	Trieste	JAPAN	Tokyo
BANGLADESH	Chittagong	MALAYSIA	Singapore
BELGIUM	Antwerp	NETHERLANDS	Rotterdam
BRAZIL	Santos	NEW ZEALAND	Tauranga (Auckland)
CHILE	Valparaiso	PAKISTAN	Karachi
CHINA MAINLAND	Shanghai	PERU	Callao
CHINA TAIWAN	Kaohsiung	PHILIPPINES	Manila
COLOMBIA	Manga (Cartegena)	POLAND	Gdansk
COSTA RICA	Puerto Limon	PORTUGAL	Lisbon
DENMARK	Aarhus	RUSSIA	St. Petersburg
DOMINICAN REP	Caucedo	SINGAPORE	Singapore
ECUADOR	Guayaquil	SOUTH AFRICA	Durban
EL SALVADOR	Acajutla	SOUTH KOREA	Busan
FINLAND	Helsinki	SPAIN	Algeciras
FRANCE	Le Havre	SRI LANKA	Colombo
GERMANY	Hamburg	SWEDEN	Gothenburg
GUATEMALA	Puerto Cortes	THAILAND	Laem Chabang (Bangkok)
HONDURAS	Puerto Cortes	TURKEY	Izmir
HONG KONG	Hong Kong	UNITED KINGDOM	Felixstowe
INDIA	Jawaharlal Nehru (Mumbai)	VENEZUELA	Puerto Cabello
INDONESIA	Jakarta	VIETNAM	Ho Chi Minh City

Table 1. Table of 46 foreign countries, each represented by its most prominent port

More than 90 percent of total containerized traffic entering or leaving the U.S. (measured in twenty-foot equivalent units [TEUs]) moves through 14 large ports (American Association of Port Authorities, 2009). These ports are Los Angeles, Long Beach, Oakland, Seattle and Tacoma on the Pacific Coast, New York, Baltimore, Norfolk-Hampton Roads, Charleston, Savannah, Jacksonville, Port Everglades (Ft. Lauderdale) and Miami on the Atlantic Coast, and Houston on the Gulf Coast. The ports of Los Angeles and Long Beach operate separately, but are physically adjacent and regarded as one for this analysis. Similarly, Seattle and Tacoma are two separate ports, but because they are very close to one another, we group them together. Finally, Miami and Port Everglades are also two separate ports that have been grouped together to represent a "South Florida" port for the analysis. Thus, we consider 11 U.S. locations as ports, including all 14 of the largest individual facilities.

In addition, Vancouver and Prince Rupert in Canada and Lazaro Cardenas in Mexico are ports on the Pacific Coast that are entry points for containers that subsequently enter the U.S. via land crossings. Thus, the model has 14 ports represented for U.S. imports and exports. In general, we will refer to these 14 ports as the North American ports and the ports in other parts of the world as foreign ports. Although Vancouver, Prince Rupert, and Lazaro Cardenas are "foreign" from a U.S. perspective, there is little sea traffic from them to U.S. ports, so the focus is on their role as possible points-of-landing for containers that are ultimately destined for U.S. locations. Table 2 below summarizes the 14 ports represented in the model.

Baltimore Port	Norfolk Port
Charleston Port	Oakland Port
Houston Port	Prince Rupert, BC Port
Jacksonville Port	Savannah Port
Lazaro Cardenas, MX Port	Seattle -Tacoma Ports
Los Angeles - Long Beach Ports	South Florida Port
New York - New Jersey Ports	Vancouver, BC Port

Table 2. 14 North American ports represented in the model

Inside the U.S., shipment origins and destinations are aggregated into 84 Transportation Analysis Zones (TAZs). Named by the major cities shown in Table 3, each TAZ represents a collection of counties. Between the ports and the cities representing TAZs, the model includes both rail and truck connections, reflecting the modal choice made by shippers for the domestic part of their supply chain.

Albany, NY	Dayton, OH	Las Vegas, NV	Portland,OR
Albuquerque, NM	Denver, CO	Lexington, KY	Raleigh, NC
Atlanta, GA	Des Moines, IA	Little Rock, AR	Redding, CA
Austin, TX	Detroit, MI	Los Angeles, CA	Richmond, VA
Baltimore, MD	Duluth, MN	Louisville, KY	Rochester, NY
Billings, MT	El Paso, TX	Memphis, TN	Sacramento, CA
Birmingham, AL	Fargo, ND	Miami, FL	Salt Lake City, UT
Boise City, ID	Fort Wayne, IN	Milwaukee, WI	San Antonio, TX
Boston, MA	Fresno, CA	Minneapolis, MN	San Diego, CA
Buffalo, NY	Grand Rapids, MI	Mobile, AL	San Jose, CA
Charleston, SC	Green Bay, WI	Nashville, TN	Savannah, GA
Charleston,WV	Greensboro, NC	New Orleans, LA	Seattle, WA
Charlotte, NC	Greenville, NC	New York, NY	Sioux Falls, SD
Chattanooga, TN	Greenville, SC	Norfolk, VA	Springfield, MO
Chicago, IL	Harrrisburg, PA	Oklahoma City, OK	St. Louis, MO
Cincinnati, OH	Houston, TX	Omaha, NE	Syracuse, NY
Cleveland, OH	Indianapolis, IN	Orlando, FL	Tampa, FL
Columbia, SC	Jackson, MS	Philadelphia, PA	Toledo, OH
Columbus, OH	Jacksonville, FL	Phoenix, AZ	Tulsa, OK
Corpus Christi, TX	Kansas City, MO	Pittsburgh, PA	Wichita, KS
Dallas, TX	Knoxville, TN	Portland, ME	Wilmington, NC

Table 3. 84 Transportation Analysis Zones represented in the model

The overall model is a network multi-commodity flow model, representing flows between foreign countries and North American ports, the total volumes handled (import and export) by each port, the modal volumes (truck and rail) into and out of each port, and volumes between each port and each TAZ. The principal reflection of congestion in the model is in the ports, and in the capacity limits for rail connections at the ports. The model finds paths through the network for containers to minimize their total transportation costs, expressed here as transit days.

After the model finds the optimal solution to operate the transportation system at minimum cost, an intelligent adversary will attack the network with the goal of maximizing the operator's (or transportation system's) total transportation cost. Our findings present the adversary's optimal attack options and the respective costs of each to the transportation system. The operator then optimizes the flow of goods through the surviving network. The idea is to find the key components that a transportation security incident might influence adversely, even when the system responds optimally to any casualty.

B. LITERATURE REVIEW OF PREVIOUS WORK

The study of multimodal network modeling is not new. Kresge and Roberts (1971) developed a significant multimodal predictive freight network model: the "Harvard-Brookings" model. The network used in their model consists of links that represent the available paths with constant O-D perceived shipping costs and nodes that represent the cities or regions serving as origins or destinations. Shippers' modal choices are determined through shortest path calculations for the intermodal network. Their model is focused on transport problems in developing countries and represents application of the economic concept of spatial price equilibrium. Spatial price equilibrium models focus on producer-consumer-shipper interactions. The producers and the consumers act in a set of geographically-separated regions, or centroids, while the shippers determine the trading pattern that brings economic (supply-demand) equilibrium.

During the 1980s, there was significant work on freight network models focusing on the shipper-carrier interactions. For those models, demands are assumed to be known and are routed on the carriers' networks such that the carriers' costs are minimized. The work by Friesz and Harker (1985) includes both the carrier decisions with respect to routing and a spatial price equilibrium framework to represent the demand side of the model. Their work is quite sophisticated, but proves difficult to support with available data and raises significant computational issues.

Jones, Qu, Casavant, and Koo (1995) focus on export wheat shipments through ports in the Pacific Northwest. They formulate a spatial price equilibrium model as a quadratic programming problem, where the regions are 11 wheat exporting areas in the United States and 14 international wheat importing areas. They represent eight United States and Canadian ports, through which the United States' wheat exports flow. The key variables are regional prices and flows. They use their model to examine effects of possible changes in international markets (such as a Chinese quarantine on U.S. wheat shipments) and changes in the regional transportation system (such as closure of the Columbia-Snake River system to barges) on flows through ports, regional prices, and so forth. Their model is of interest because of its focus on spatial price equilibrium and ports, but it is quite dated (data from 1989), and the commodity and strong regional focus make it less directly related to the current work than the model developed somewhat later by Luo and Grigalunas (2003).

Luo and Grigalunas describe a flow model intended to estimate the volumes of containers flowing through various U.S. ports, and how those volumes might change under modified port fees. Their model, as the one described in this thesis, is based on a premise that shippers attempt to minimize total logistics costs, including both transportation and inventory costs. However, they have no capacity constraints in their model, so the route selected for each O-D pair is just a shortest path calculation. They then add the flows on paths that use a given port to get total port volume.

They use a set of six foreign origin areas (continents) and define U.S. areas as states, except in the Northeast, where they disaggregate to counties. They estimated O-D tables for 31 commodity groups, based on data published by the U.S. Maritime Administration. These data give weight and value by commodity class from foreign origins to the United States in total (and reverse for exports), but they do not give TEUs, nor do they say anything about where in the United States the shipments originate or terminate.

They represented a set of 14 U.S. ports (with Seattle-Tacoma and Los Angeles-Long Beach each considered as one). Their calibration results (based on observed total port volumes) match a few ports (New York, Houston, and Seattle) reasonably well, but show disparities in several others (Los Angeles-Long Beach, Oakland, Charleston, and Jacksonville). Overall, their O-D estimates are based on very little demand data. However, the general direction of their work is very useful to us.

Lee, Chew, and Lee (2006), who develop a multi-commodity network flow model to estimate the demand at the ports of the Asia-Pacific region, take a similar approach.

They use their model to study the sensitivity of the cargo flow between ports with respect to efficiency, port charges, and shipping costs.

Other recent efforts in freight equilibrium models include work by Fernandez, de Cea, and Soto (2003); Safwat and Hasan (2004); and Agrawal and Ziliaskopoulos (2006). These represent varying ways of representing the interaction of shippers and carriers, as well as various ways of modeling different transportation modes and carriers' decisions regarding shipment routing.

Mahmassani, et al. (2007), propose a more tactical-level model. They present a simulation-based dynamic network assignment model that enables the micro-assignment of shipments. Their model is designed to evaluate service networks, including terminal delays and consolidation policies at classification yards, intermodal transfer terminals, and ports.

We also note the work done by Malchow and Kanafani (2001), on competition among alternative ports. They use a discrete choice model to analyze the distribution of maritime shipments among the ports in the United States. However, this is not done in the context of a larger freight network model.

Finally, we note the recent effort that has been devoted to the application of optimal network interdiction to critical infrastructure protection (Brown, Carlyle, Salmeron, and Wood, 2006) at the Naval Postgraduate School. This thesis continues that effort, formalizes the notion of an optimal attack for a multi-commodity network flow problem, and provides analysis and computational implementation to solve it efficiently. We construct a model to take advantage of some of these previous ideas, but also to focus less on issues related to world market prices, port handling charges, and so forth, and more on the potential effects of physical disruptions to the supply-chain infrastructure and potential operational changes due to a transportation security incident.

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II. BACKGROUND

A. WHY IS IT MANDATORY TO PLAN FOR DISRUPTIONS IN THE COMMERCIAL TRANSPORTATION SYSTEM?

1. What is "Infrastructure"?

The *American Heritage Dictionary* defines the term infrastructure as:

> The basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons.

2. Homeland Security Presidential Directive 7

Homeland Security Presidential Directive 7 establishes a national policy for Federal departments and agencies to identify, prioritize, and protect critical infrastructure from terrorist attacks (Department of Homeland Security, 2003). The National Infrastructure Protection Plan (NIPP) is the Department of Homeland Security's plan to direct our national strategy for executing the President's Directive. The 18 Critical Infrastructure and Key Resource (CIKR) sectors are agriculture and food, defense industrial base, energy, healthcare and public health, national monuments and icons, banking and finance, water, chemical, commercial facilities, critical manufacturing, dams, emergency services, nuclear reactors, information technology, communications, postal and shipping, transportation systems and government facilities.

The sector specific agency responsible for transportation systems is the Transportation Security Administration. Along with the Department of Homeland Security, it is responsible for all matters relating to transportation security and transportation infrastructure protection (Department of Homeland Security, 2009).

3. Department of Homeland Security Risk Assessment

In the National Infrastructure Protection Plan (NIPP), the U.S. Department of Homeland Security (DHS) has promoted Probabilistic Risk Assessment (PRA) for assessing the threats posed by intelligent adversaries in a terrorist attack (Department of Homeland Security, 2009). Currently, the Department of Homeland Security (DHS) uses the Risk Analysis and Management for Critical Asset Protection (RAMCAP-Plus) program to perform PRA. RAMCAP-Plus is a program that allows users to conduct vulnerability and risk assessments, starting with the identification of critical assets and culminating in the management of risk for the entire facility (Alion Science and Technology, 2007). Use of RAMCAP-Plus identifies vulnerable nodes in a network, so decision makers can make the vulnerable nodes more resistant to attack. RAMCAP-Plus ranks the infrastructure by amount of flow and defends the highest flow arc first, followed by the second, third, and so on until all available resources are used.

We have misgivings about this simplified ranking. The U.S. transportation system is quite flexible, and capable of accommodating re-routed flows around components rendered inoperable for any cause. Further, evaluating components in isolation misses key relationships among *sets* of components. So, we advise actually modeling the function of the transportation system, and how its operators would respond to any damage.

B. ATTACKER-DEFENDER MODEL

We use the term "Attacker-Defender" (AD) model to define a type of Stackelberg game (Stackelberg, 1952) that has been extensively studied for analyzing vulnerabilities of critical infrastructure (e.g., Wood, 1993; Salmeron et al., 2004; Brown et al., 2006; Salmeron et al., 2008; Brown et al., 2008). We choose to use the attacker-defender model to provide a better representation of the transportation infrastructure and how it can be managed. Our assessment of critical infrastructure components and the defensive investments that preserve system function in an optimal manner proceeds in two steps.

1. The Operator's Model

We start by offering a model for the behavior of the system under normal operating conditions, which we call the operator's model. The system need not have an actual "operator" to apply the technique presented here. The only requirement is that the system has a clearly stated operating objective, "minimize cost" in our case, and that we represent any constraints affecting how the system can operate, be they capacity limits, or flow controls, etc.

The natural language for representing the tension between a system's objectives and its capabilities is constrained optimization. If we use the vector of decision variables $\boldsymbol{y}$ to denote an "operating plan" for the infrastructure system, we can state the operator's problem simply as the following mathematical programming problem:

$$\min_{y \in Y} f(y), \tag{D}$$

where Y represents the set of all feasible operating plans, and the function f represents our measure of performance for any feasible operating plan. Here, we have chosen to state the operator's problem as a minimization problem (e.g., minimize the transportation cost of the system in our model). The variables y represent decisions about movement, assignment, or allocation of goods, materials, budget, equipment, energy, vehicles, platforms, personnel, information, money, or anything else related to system operation. The set Y of feasible operating plans allows us to capture limited operator resources, capacity limitations within the system, as well as dependencies between system components. Constrained optimization problems of this type have been studied extensively for over sixty years and are limited only by the imagination of the modeler to capture domain-specific details of interest (e.g., Rardin, 1997 or Ahuja et al., 1993).

2. The "Attacker's Problem"

We next answer the question, what course of action will maximize the disruption to the system, anticipating an optimal response by the system operator? We can model maximally disruptive attacks on an infrastructure system through a bi-level mathematical program of this form (Danskin, 1967 and Moore and Bard, 1990):

$$\max_{x \in X} \min_{y \in Y(x)} f(y \mid x), \tag{AD}$$

where $x_k = 1$ if component k of the system is attacked, and $x_k = 0$ otherwise; $x \in X$ represents an anticipated set of resource constraints on an attacker, including the restriction that attacks are binary; $y \in Y(x)$ denotes constraints on any operating plans as influenced by the "attack plan" x. Here we assume, without any loss of generality, that the attack variables x only influence the objective function; they can have an indirect influence on the feasible region of y through large penalty coefficients in the objective. The inner minimization still represents a system operator, a group of informed system users, or a set of automated protocols that will identify the best way to operate the system depending on its state. The outer maximization assumes that an "attacker" understands how the "operator" runs his system and seeks to inflict maximum harm to that system.

C. DATA SOURCES AND ORIGIN-DESTINATION CONTAINER MOVEMENTS

1. Demand Data

Based on PIERS data for 2007, sixty-seven countries represent about 99 percent of the containers that entered the United States (PIERS Global Intelligence Solutions, 2008). From the U.S. Maritime Administration's (MARAD) maritime statistics page, Figure 1 shows container imports to the United States in 1998, 2001, 2004, and 2007 from the ten largest trading partners (U.S. Maritime Administration, 2009). China is the largest, representing over 47 percent of containers imported in 2007 and experiencing more than a 20-percent annual growth rate over the last decade.

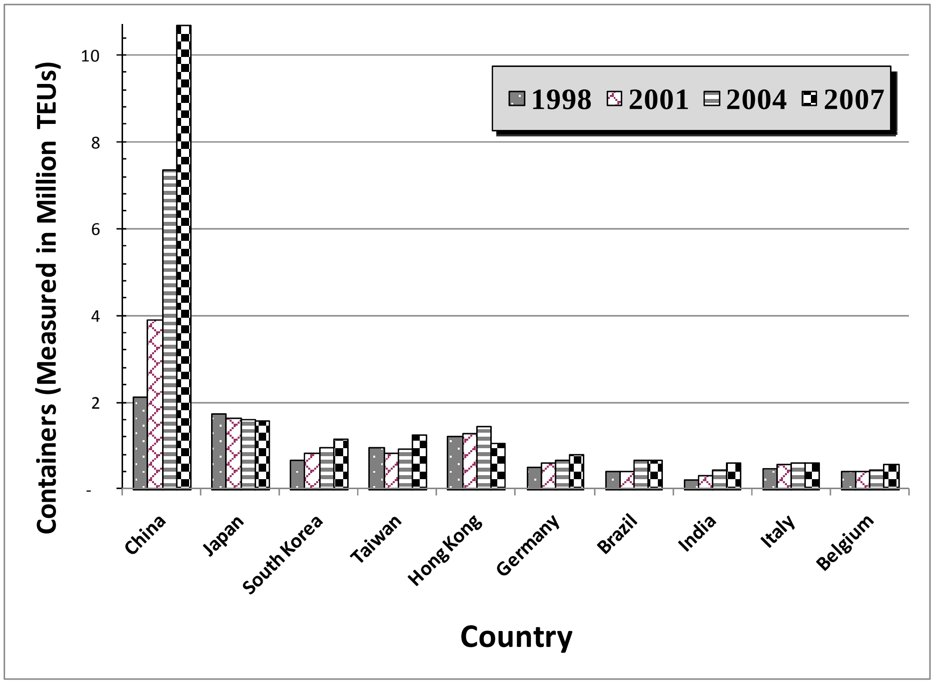

Figure 1. Waterborne containerized import and export TEUs from the 10 largest trading partners (From: U.S. Maritime Administration, 2009)

As shown in Figure 2 from MARAD's 2008 data, the largest exporters to the United States represent 99.05 percent of all imports and are grouped into three distinct regions: Asia (representing 75.98 percent of U.S. imports), Europe (13.09 percent), and Central and South America (9.98 percent).

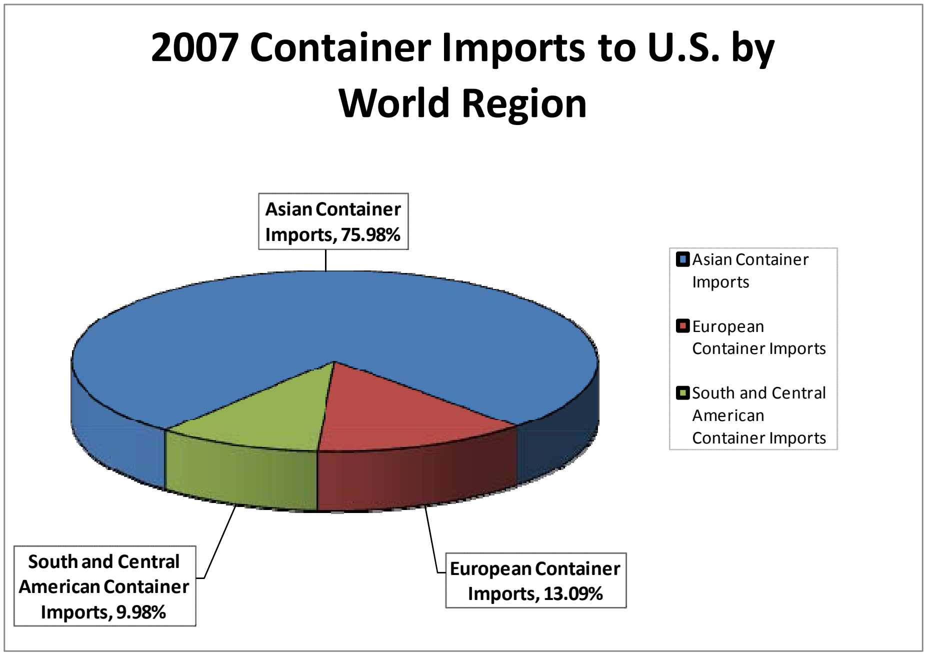

Figure 2. Waterborne containerized percentage of imports by world region in 2007 (From: U.S. Maritime Administration, 2008)

The PIERS data are very useful for understanding the routes that containers follow from an origin country, through a foreign port, and through a U.S. port. For example, Figure 3 illustrates two sample routes for a shipment from Germany to Kansas City, Missouri. The first route goes through the port of Lisbon in Portugal and then the port of New York-New Jersey, while the second route goes through the port of Bremerhaven in Germany and then the port of New York-New Jersey. The data include a distinction between origin country and departure country, the country where the cargo is loaded onto a ship destined for the United States. The data provide observations of flow from origin country to departure port, and from departure port (that is, nodes of type 1 in Figure 3) to entry port in the United States (nodes of type 2 in Figure 3).

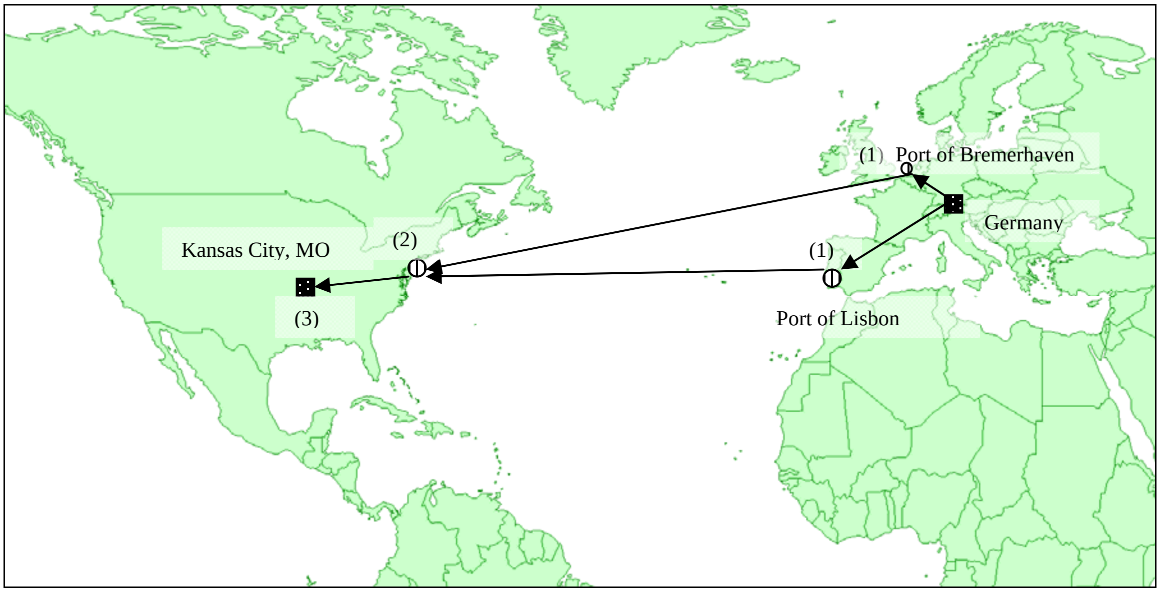

Figure 3. Example of two import flow paths from a foreign origin country (Germany) to a U.S. destination (Kansas City, MO) distinguished by foreign port of origin (Bremerhaven or Lisbon).

The PIERS data does not include information on the U.S. domestic movement (nodes of type 3 in Figure 3). PIERS records movements (in TEUs) from origins to U.S. ports. There is high consistency between the total recorded volumes of imports by U.S. port and the origin-specific data, but once the shipment has entered the United States, there is no record of its final destination.

The rail waybill sample collected by the Surface Transportation Board (STB) is one source of data on the domestic leg of container movements. This is a sample of records of rail car movements between Bureau of Economic Analysis' (BEA) Economic Areas (EA) within the United States, which includes the commodity moved and other data. The U.S. Department of Commerce's Bureau of Economic Analysis defines these Economic Areas as geographic regions composed of a collection of counties that represent centers of regional economic activity and aggregate actual origins and destinations of shipments (Bureau of Economic Analysis, 2004). The "Transportation Analysis Zones" (TAZs) used for this thesis are aggregations of BEA's Economic Areas, allowing use of the rail waybill data to provide information on the domestic movement of containers, at least those that move by rail. For simplification purposes each TAZ is represented by a major city within it, denoted a centroid, shown in Figure 4. Each centroid serves as the modeled origin (for exports) or destination (for imports) for freight movements for the entire zone.

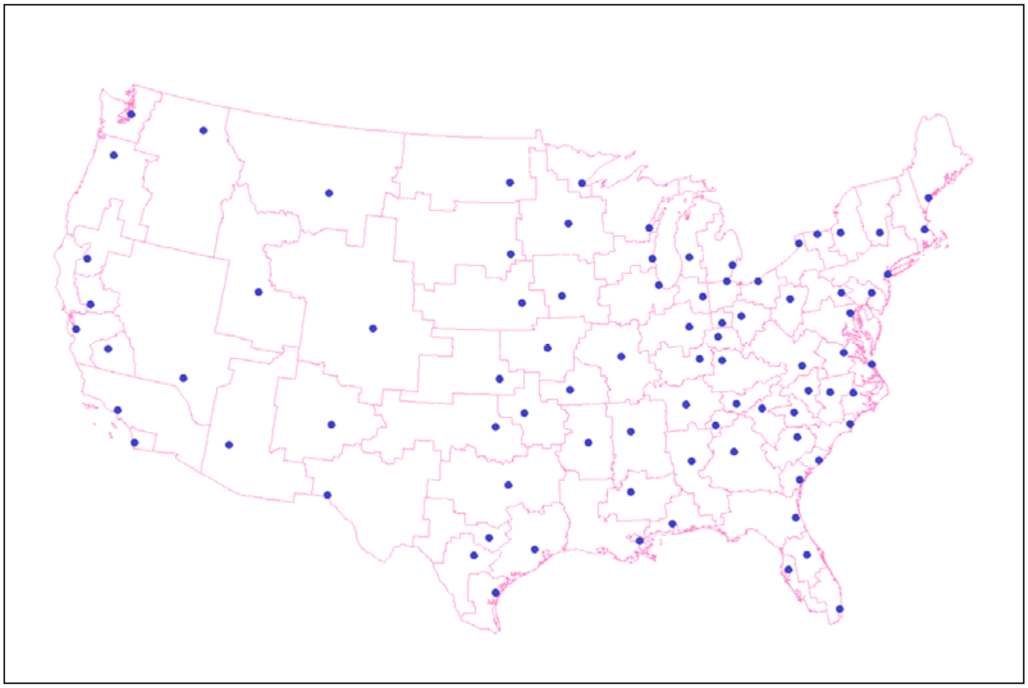

Figure 4. Transportation Analysis Zones (TAZs) and centroid city locations

With multiple destinations for rail and truck movements from each domestic port represented, we replicate the structure in Figure 5 for rail and truck links for each destination. However, data on the rail-truck mode split for each destination from each port are not available, so we present a simplified approach in section 7 of this chapter. This allows control over the aggregate rail-truck split from each port.

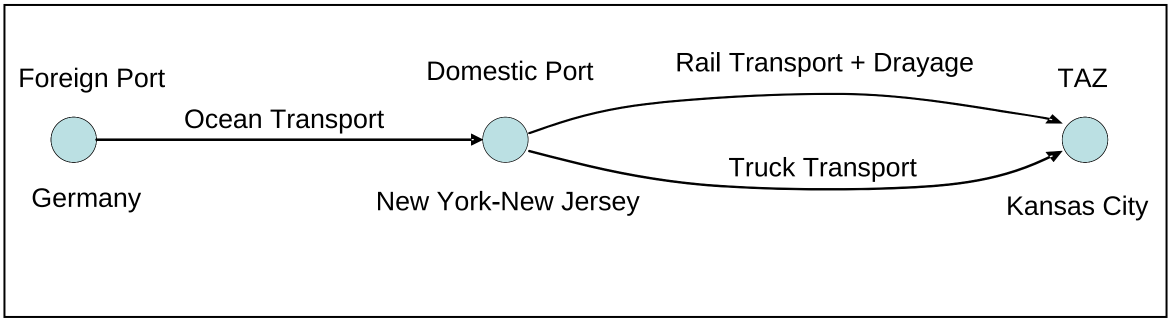

Figure 5. Sample arcs from a foreign port to a destination TAZ

In the overall network, shown in Figure 6, there are connections between foreign ports and various North American ports. Each of the arcs has costs and times based on country sailing distances. This allows the overall model to represent several possible paths for each O-D pair—using alternate ports as well as choice of rail or truck for the movement between the port and the destination. From each of the North American ports represented in the model, there is a sub-network like the one shown in Figure 5 extending inland to the 84 TAZs to represent import flows.

For exports, as shown in Figure 6 below, there is a comparable structure, but with the links oriented in the opposite direction. All flows, whether import or export, move through the port facilities, making them the central elements of the overall network model. If the ports become congested, delays increase and shippers have an incentive to use alternate routes.

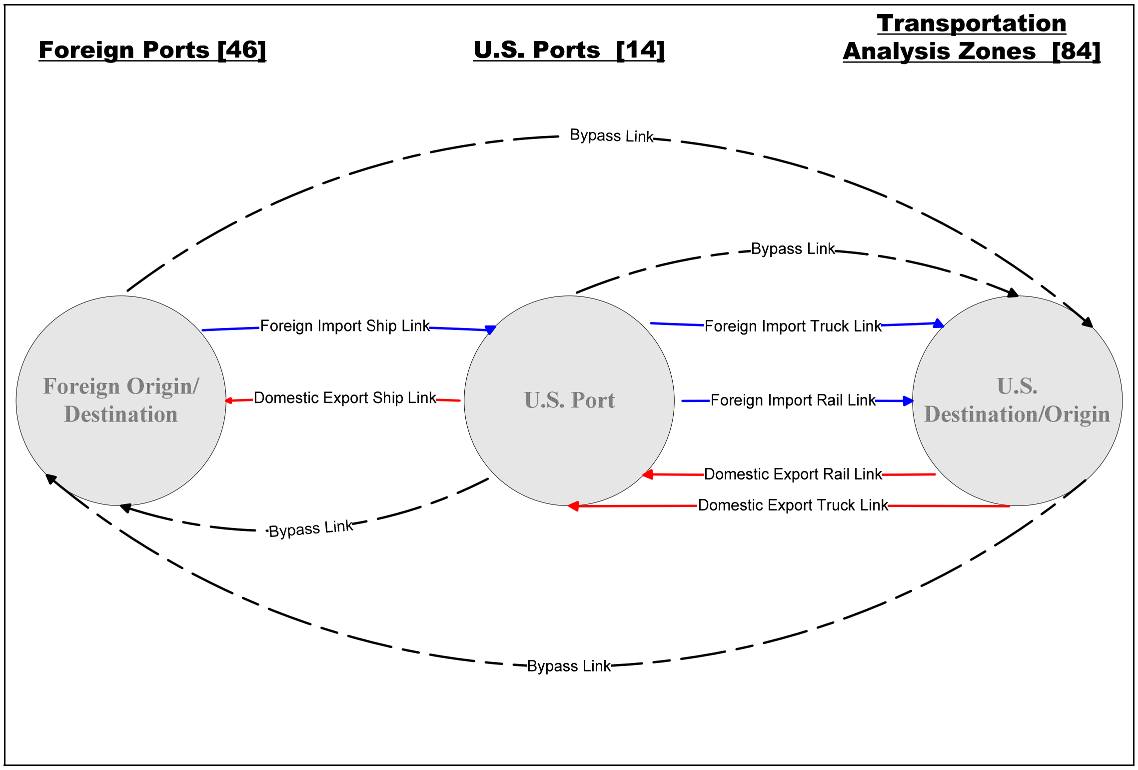

Figure 6. The bi-modal commercial container transportation network. An import container begins travel in a foreign port, enters the U.S. via a domestic port and can either be shipped by rail or truck to a U.S. destination. An export container begins travel in a U.S. TAZ, is then shipped to a port via rail or truck and transported via ship to a foreign destination. At any point, the model may choose to ship it directly to the destination, for an additional cost or it may choose to delay the container, again for an additional delay cost.

2. Port-to-port Distances

We used the port-to-port distances from the website www.distances.com. A sample of the data collected electronically from distances.com has been checked against data in National Imagery and Mapping Agency Publication 151, Distances between Ports (U.S. Department of Defense National Imagery and Mapping Agency, 2001), and differences are less than 2.5% for all port-to-port pairs checked. Lazaro Cardenas is not listed by distances.com, so we used Manzanillo, Mexico, as an approximate location. Manzanillo is relatively close to Lazaro Cardenas, so the error should not affect solutions significantly.

3. Port-to-port Sailing Times

The sailing times are simply the port-to-port distances, divided by an average speed of 20 knots, and rounded up to the next whole day. We derive the 20-knot average speed from average sailing speeds of large container ships listed in "Container Insight," June 2007 as listed in Table 4 below.

World (cellular) Containership Fleet: 31st May 2007

Size Range (Teu)	No. of Vessels	%	Total Capacity (Teu)	%	Average Speed (Knots)	Age (Years)
<500	440	10.7%	136,754	1.4%	14.0	21.3
500-999	751	18.2%	547,892	5.5%	16.9	11.3
1,000-1,499	607	14.7%	717,406	7.2%	18.4	12.5
1,500-1,999	484	11.8%	822,427	8.3%	19.7	11.2
2,000-2,499	302	7.3%	691,569	7.0%	20.8	11.3
2,500-2,999	347	8.4%	944,336	9.5%	21.9	9.8
3,000-3,999	315	7.6%	1,074,589	10.8%	22.5	12.7
4,000-4,999	352	8.5%	1,544,299	15.5%	24.0	7.2
5,000-5,999	235	5.7%	1,278,128	12.9%	25.2	4.8
6,000-6,999	113	2.7%	733,688	7.4%	25.2	4.6
7,000-7,999	48	1.2%	352,971	3.6%	25.1	4.5
8,000+	125	3.0%	1,089,108	11.0%	25.0	1.4
Total	**4,119**	**100.0%**	**9,933,167**	**100.0%**	**19.9**	**11.2**

Table 4. Characteristics of the world containership fleet (From: Drewry Publications, June 2007).

4. Domestic Port to Transportation Analysis Zone Distances

The overland distances from ports of entry to destination zones (TAZs) come from calculations in TransCAD using the full U.S. rail network (the “Oak Ridge” network). We use these distances for both rail and truck shipments. There may be some discrepancies between road distances and rail distances for some port-TAZ pairs, but these are not likely to be large enough to be problematic.

The three ports outside the U.S. (Prince Rupert, Vancouver, and Lazaro Cardenas) represent two different situations. The Oak Ridge network contains some Canadian rail lines connected to the U.S. rail system and part of that network are Vancouver and Prince Rupert. We obtain their distances directly from that part of the Oak Ridge network. Canadian National Rail connects Prince Rupert while Vancouver has access to Canadian National, Canadian Pacific Rail and Union Pacific. For Lazaro Cardenas, we estimate the distance from there to Laredo, Texas (900 miles), where the Kansas City Southern system enters the U.S., and then add the distance from Laredo to the various TAZ destinations. We obtain the Mexican distance from http://www.maps-of-mexico.com/driving-distance-chart.shtml (Virtual Photos and Maps, 1997). This distance is a highway distance, not a rail distance, but is accurate enough for model purposes.

5. Truck Travel Times

To estimate travel times by over-the-road truck from U.S. ports to destinations (TAZs), we consulted www.skedz.com (Schedule Distribution Services, LLC , 2008), where intermodal train schedules between various origins (domestic ports) and destinations (TAZs) can be accessed and compared to estimates of over-the-road truck travel times. The website estimates truck travel times to the nearest tenth of a day. Given hours-of-service regulations on drivers, available hours for pick-up and delivery of the loads, etc., estimating travel times to a tenth of a day is probably unnecessary, and the truck travel times have been approximated (to the nearest one-half day) by the formula:

$$t_{ij}^{T} = 0.5 * \mathrm{int}\left(\frac{d_{ij}}{300}\right) + 0.5 \quad (days) \tag{1}$$

where: d_{ij} = mileage from origin i to destination j.

$\mathrm{int}\left(\frac{d_{ij}}{300}\right)$ = largest integer that is less than or equal to the distance traveled, divided by half the average travel speed.

This formula effectively rounds up to the next one-half day, and assumes an average travel speed of 600 miles/day. The results of using this formula compare quite well to the estimates quoted on www.skedz.com.

6. Rail Travel Times

We find origin-destination intermodal rail schedules at www.skedz.com. For a given O-D pair, there may be different times quoted, based on the time-of-day and day-of-week when the shipment is tendered. The times quoted are rail point-to-point times (in days), and do not include the drayage at either end of the trip. We add 24 hours for drayage, and rounded the resulting times up to the next one-half day. These values construct an estimate of the door-to-door time by rail as:

$$t_{ij}^{R} = 0.5 * \text{int}\left(\frac{d_{ij}}{220}\right) + 1.5 \quad (days) \qquad (2)$$

where: d_{ij} = mileage from origin *i* to destination *j*.

$\text{int}\left(\frac{d_{ij}}{220}\right)$ = largest integer that is less than or equal to the distance traveled divided by half the average travel speed.

This formula effectively rounds up to the next one-half day, and assumes an average travel speed of 440 miles/day. Figure 7 below captures the expansive nature of the national rail network.

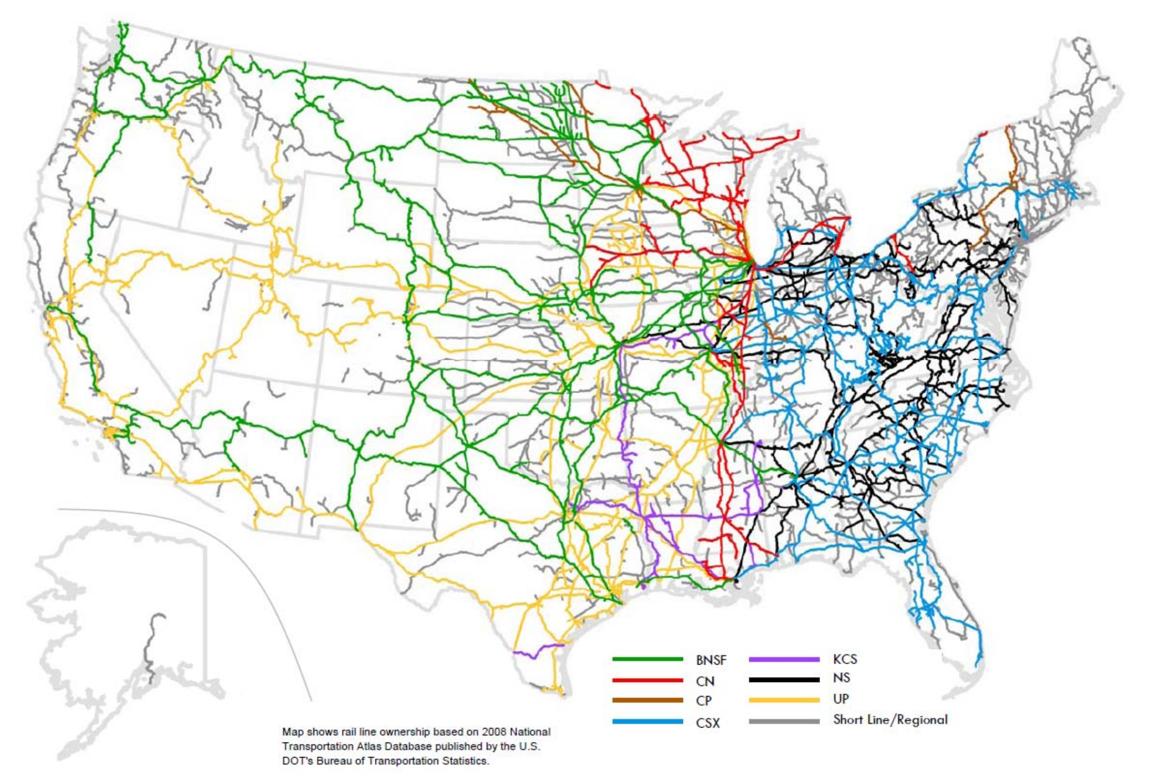

Figure 7. Major lines of the national rail network based on 2008 National Transportation Atlas Database. (From: Association of American Railroads, 2009)

7. Rail and Truck Flow Variations

To estimate container flow from the domestic ports to destinations (TAZs) by rail and truck we use the available data from the Bureau of Transportation Statistics (BTS). From the BTS 2007 Preliminary Commodity Flow Survey we used the 2007 table of shipment characteristics by Mode of Transportation to determine the percentage of flow by mode (Bureau of Transportation Statistics, 2008). The table compares both single and multiple mode transport. We use the single-mode 2007 tons shipped on rail and truck to determine the ratios. We remove other single modes the table also includes from our computation. We then normalize the data by taking the sum of the two modes and calculating the percent each mode contributes to the sum. After rounding, we conclude that in 2007 rail moved about 18 percent of the tonnage while truck moved about 82 percent.

8. Estimation of Port Capacity

Port facilities can be viewed using a "pipe" analogy, as shown in Figure 8, which is useful to understand delays and capacity. We can view the various processing steps within the port terminal as sections of pipe, with varying sizes representing different capacities. The smallest pipe section dictates the capacity for the terminal as a whole. It may be at any of several places in the facility. In the example shown in Figure 8, the terminal equipment (i.e., the container yard) is the limiting element.

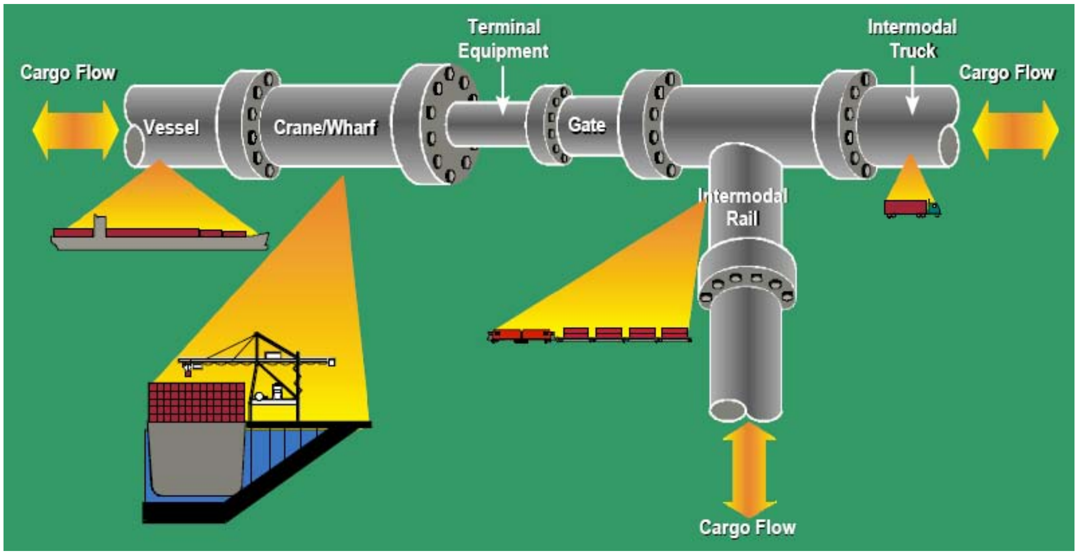

Figure 8. "Pipe" analogy for port facilities (From: Brennan, 2006)

The analysis of capacity in a port is on a terminal-by-terminal basis. The "bottleneck" that determines the capacity of a given terminal can be in any of several places, but the primary focus here is on two elements—the berth processing of vessels and the container yard. We first discuss the capacity of berths followed by the capacity analysis of container yards.

The expected time required to process a ship (i.e., berth the ship, unload the inbound containers, load the outbound containers and have the ship leave the berth) can be estimated based on the total number of inbound and outbound TEUs (T), the total number of cranes assigned (N), the processing rate (lifts per hour, LPH) of the cranes, the fraction of the containers that are 40-foot containers versus 20-foot containers (ϕ) and the amount of time needed to position the ship at the berth and to move the ship from the berth (τ). The relationship for expected service time, E[S], expressed in hours, is given in equation (C1).

$$E[S] = \frac{\frac{T}{1+\varphi}}{N * LPH} + \tau. \qquad (C1)$$

A similar formula is used by both Turner (2000) and Pachakis and Kiremidjian (2003). Equation (C1) assumes that containers are either 20-foot or 40-foot containers. More than 90% percent of containers are in these two categories at West Coast ports, based on the data assembled by the Pacific Maritime Association (Pacific Maritime Association, 2009), and at Los Angeles 71.3% of containers are in the 40-foot category. On the East Coast, the Port of New York and New Jersey reports that from 2000 to 2007 about 70% of their containers were 40-foot (The Port Authority of New York and New Jersey, 2009). Thus, there appears to be relative consistency across ports. As illustrated by equation (C1), this statistic is important because it takes about the same amount of time to lift one 20-foot container as to lift one 40-foot container.

For a given port, we can estimate the TEUs per vessel based on total reported TEUs handled and vessel call statistics. For example, the Port of Houston reported handling 2,485,605 TEUs in 2007, and the Maritime Administration reports 818 container vessel calls in Houston during that year (U.S. Maritime Administration, 2007). Thus, we can estimate that the average vessel unloaded and reloaded 3,039 TEUs. There may be some variation among terminals within a port, but we use port averages in the absence of better information.

Terminal statistics on the number of berths available and the number of cranes available are relatively easy to obtain, and we can estimate the number of cranes assigned (on average) by simply dividing available cranes by available berths. Gantry cranes may perform more than 30 lifts per hour under ideal conditions, but a somewhat smaller number (e.g., 25) is more realistic on a sustained basis.

We assume that the time required to position the ship at the berth and to move it from the berth afterwards is a total of 3 hours. This is consistent with estimates given by Turner (2000).

Thus, for example, the first phase of Houston's new Bayport Terminal opened in 2007, with two berths and four cranes. Using the port average of 3,039 TEUs to lift per vessel, with 64% being 40-foot containers (again, the port average), and 25 lifts/hour from the cranes, we would estimate that the expected service time for a vessel at this terminal is:

$$E[S] = \frac{\frac{3039}{1.64}}{2\,(25)} + 3 = 40.1 \quad (hours)\ .$$

The service time formula is an important determinant of capacity because each available berth in the port has an effective capacity of (1/E[S]) during the hours that it operates. The overall effective capacity of the terminal wharf is then related to the number of berths (*k*), the value of E[S], and the working hours per week of the terminal (*h*). Some terminals operate on a 24/7 basis, but many do not. For example, if the terminal operates 16 hours/day, 6 days/week, the total effective service rate is about 57% of the rate that would be achievable with 24/7 operations. A reasonable estimate of the wharf capacity of a terminal (in TEUs/week) is then:

$$U_w = \frac{khT}{E[S]}. \qquad (C2)$$

The container yard is the second major piece of the terminal capacity determination. A terminal's yard acts as a buffer between arrivals and departures. The throughput capacity of the yard (in the sense indicated by the "pipe" diagram in Figure 8) is determined by the number of containers that can be stored in the yard at any given time and the average dwell time of the containers that pass through the yard. For example, a yard that can hold 10,000 TEUs, and for which the average dwell time is 4 days, can sustain an average throughput rate of 2,500 containers per day. If this throughput rate is lower than the rate at which vessels can be unloaded—reloaded at the berths, the terminal is yard-constrained, and the effective processing rate of the berths must be lowered to match the yard throughput rate. This may cause queuing of vessels and increased delay time for containers passing through the facility.

Determining the yard's sustainable throughput rate (capacity) revolves around finding the number of "effective slots" (TEUs) that can be used in the yard, and the average dwell time. The product of those two values yields the capacity. Container terminals typically treat the average dwell time as an exogenous variable—that is, determined by factors outside the control of the terminal operator. Typically, the determining factors include the ability to deliver containers locally, or to transfer them to rail or over-the-road trucks.

The number of effective TEU "slots" in the yard is related to the terminal area, the container stacking and handling equipment in use, the degree to which the terminal operator emphasizes wheeled storage versus grounded storage, etc. In some cases, terminal operators publish the total number of slots in their facility. For example, at Houston's new Bayport Terminal, the Port of Houston Authority reports availability of 12,684 total TEU slots in the yard (The Port of Houston Authority, 2008). In other ports, less specific information is available and we make some estimates.

For example, we estimate total TEU slots the product of total ground slots (TGS) and average stack height. We also estimate TGS, if not reported directly, based on the yard size (in acres) and the proportion dedicated to wheeled operations. Terminal operators like wheeled operations (where containers are stored on trailer chasses) because this reduces the labor cost of handling containers in the yard. The containers simply wait for the drayage operator to arrive, hook up to the trailer and depart. However, wheeled operations require more area per slot, and preclude stacking. Thus, the total number of TEU slots for wheeled operations is about 75 TEU/acre (Chu and Huang, 2005 and JWD Group, 2003). By contrast, in "grounded" operations, where containers are set directly on the ground (not on trailer chassis), the ground slots are typically about 105 TEU/acre (Chu and Huang, 2005). Thus, if a given terminal reports an area of A (acres), and the proportion of space allocated for wheeled operations is β, the estimated TGS is:

$$TGS = A\left[75\beta + 105\,(1-\beta)\right] \quad (TEUs). \tag{C3}$$

Wheeled operations clearly have a height of 1, and grounded operations are generally based on a stack height of 3 or 4 (depending on the type of handling equipment in use). It is also common to use a stack height of three for loaded containers and four for empties (JWD Group, 2003). A reasonable assumption is that the average stack height for grounded operations is about 3.5, so the average stack height in a yard would be:

$$H = \beta + 3.5\,(1-\beta) = 3.5 - 2.5\,\beta. \tag{C4}$$

Thus, given A and β, we can estimate total TEU slots in the yard as:

$$TGS * H = A\left[75\beta + 105\,(1-\beta)\right]\left(3.5 - 2.5\,\beta\right) \quad (TEUs). \tag{C5}$$

Not all of the possible slots in a yard are usable all the time. Empty slots are necessary for moving containers within a stack, and it is necessary to account for variations over time. Dharmalingam (1987), Chu, and Huang (Chu and Huang 2005) have suggested values for an "effective utilization" factor of between 0.6 and 0.75, based on empirical assessments of operations in different yards. If no specific information is available for a given yard, a reasonable default value is likely to be about 0.7. Thus, if D is the average dwell time (days), we estimate the throughput capacity of a container yard (in TEUs/week) as:

$$U_y = \frac{7\,(0.7)\,Total\ Slots}{D} \quad (TEUs\,/\,week). \tag{C6}$$

The total capacity of a specific terminal in the network is the minimum of the wharf capacity and the yard capacity:

$$U_{term} = \min\left(U_b, U_y\right). \tag{C7}$$

If this throughput capacity is lower than the computed capacity of the berths in the terminal, the berth capacity should be reduced to the yard capacity, and the expected service time for vessels increased accordingly. This is because the effective rate at which vessels can be processed is limited by the terminal's ability to handle the containers once they come off the ship. From equation (C2), we do this adjustment by solving for the effective service time $\hat{E}[S]$, using (C8).

$$\hat{E}[S] = \frac{khT}{U_{term}}. \qquad (C8)$$

Because a port will often have more than one terminal, we calculate the capacity terminal-by-terminal. The total port capacity is then the sum of the individual terminal capacities. Table 5 shows the port capacities derived here and used for our model.

Port	Terminals	Total Berths	Port Handling Capacity (TEUs per week)
Baltimore	2	6	120,678
Charleston	3	10	93,713
Houston	2	8	35,355
Jacksonville	2	14	53,300
Lazaro Cardenas, MX	1	2	14,000
Los Angeles/Long Beach	15	75	455,434
New York/New Jersey	6	30	206,889
Norfolk	2	12	54,902
Oakland	9	26	116,006
Prince Rupert, BC	1	1	17,808
Savannah	1	9	102,770
Seattle/Tacoma	9	18	160,314
South Florida	6	17	95,470
Vancouver, BC	3	6	51,149

Table 5. Calculated port handling capacities in TEUs per week. For example, Baltimore has 2 terminals and 6 total berths and a calculated port handling capacity of 120,678 TEUs per week.

D. TOTAL TRANSPORTATION COSTS

The cost measured is in TEU-days it takes all the containers to flow from origin to destination. We use this cost as an aggregate of the total travel time from foreign port to domestic destination for imports and from domestic origin to foreign destinations for exports. We show our results in both total transportation days and average days of transit per TEU.

III. ATTACKER-DEFENDER INTERMODAL MODEL

A. THE MULTICOMMODITY NETWORK MODEL

We present an illustrative case study of the major ports, highways and rail lines around the country to demonstrate how they can be modeled as a system, with system users, using the notation introduced above in Chapter II. Suppose we are worried that terrorists might attack and deny access to one or more of these ports and or TAZs. How do we value these nodes (ports or TAZs)? Moreover, given that intelligent terrorists will surely observe our defensive preparations, which nodes should be defended?

Ports, roads and rail are built to convey goods, and in our case container traffic, so we model this traffic to mimic the function of the major ports, highways and rail lines. For this particular system, there is no overarching system operator, but we anticipate that transportation system users —shippers, international shipping lines, port authorities and terminal operators, rail carriers, trucking companies, etc.—will behave via Adam Smith's "invisible hand" to choose the ports, traverse the roads and rail in the United States in an optimal manner. Inside the United States, we construct a network of 98 nodes (representing 14 ports and 84 cities), each of which is connected to others by one or more arcs (representing a road or rail connection).

We assume that the function of this system is to permit containers (measured in TEUs) to move from their place of origin (foreign port for imports or domestic city [TAZ] for exports) to their destination (domestic city [TAZ] for imports or foreign port for exports). Accordingly, we model the demand for container flow between each domestic port and TAZ pair, with specific demands given in Appendix A for imports and Appendix B for exports.

B. THE OPERATOR'S PROBLEM

The operator's problem is to route all container traffic over the network in a manner that satisfies all supplies, demands, and capacities, and that incurs the lowest total transportation cost in TEU-days. Here, we seek the optimal operation of the system given that roads and rail lines have varying capacities and costs. We measure transit cost per container in days traversed. We allow a container to "fly to the destination" if the cost to let it reach its destination becomes prohibitively high, and we assume the penalty cost of this is ten times the largest transportation cost in the network. In this case, we say that the container has been "dropped." Thus, for any set of container flows in the network, we have (total system cost) = (total transit cost) + (total drop penalty cost).

The total system cost is the sum of the operating costs in TEU travel days.

For any particular set of interdicted arcs, denoted $\hat{X}$, we formally state the operator's system operation problem $\boldsymbol{OPERATOR}(\hat{\boldsymbol{X}})$ as follows:

<u>Index use</u> [~cardinality]

$n \in N$	nodes, an ordinal set (alias *i*,*j*,*p*,*q*) [~144]
$(i, j) \in A$	directed arcs [~5656]
$m \in M$	transport mode (alias mm) [~3]

<u>Given data</u> [units]

b_{nq} Supply (≥ 0) or demand (<0) originating from *n* destined for *q* [TEUs per week] $\sum_{i \in N} b_{i,q} = 0, \forall q \in N$

c_{ijm} Cost to traverse arc $(i, j) \in A$ on mode *m* [days]

cap_n Container handling capacity of node *n* [TEUs per week]

$\underline{f}_{ijm}, \overline{f}_{ijm}$ minimum, maximum fraction of flow on directed arc $(i, j) \in A$ that can use mode *m* [fraction]

u_{ijm} Upper bound on container flow over directed arc $(i, j) \in A$ using mode *m* [TEUs per week]

q_{ij} Incremental delay to traverse an interdicted arc $(i, j) \in A$ [days per TEU]

wc_{nq} Penalty cost of dropping demand at *q* originating from *n* [days per TEU]

$\hat{X}_{ij}$ 1 if arc $(i, j) \in A$ has been interdicted, 0 otherwise [binary]

<u>Decision variables</u> [units]

Y_{ijmq} Flow on arc $(i, j) \in A$ of mode *m* traffic bound for node *q* in *days* [TEUs]

W_{iq} Surplus elastic variable for dropped demand originating at i destined for q in *days* [TEUs]

<u>Formulation</u>

$$Z_{\min}(\hat{\boldsymbol{X}}) = \sum_{\substack{(i,j)\in A,\\ m\in M}} \left[\left(c_{ijm} + q_{ij}\hat{X}_{ij} \right) \sum_{q\in N} Y_{ijmq} \right] + \sum_{n\in N, q\in N} wc_{nq} W_{nq} \qquad \text{(D0)}$$

$$s.t. \quad \sum_{\substack{(n,j)\in A,\\ m\in M}} Y_{njmq} - \sum_{\substack{(i,n)\in A,\\ m\in M}} Y_{inmq} = b_{qn} - W_{qn} \quad \forall n \in N, q \in N, q \neq n \qquad \text{(D1)}$$

$$\sum_{q\in Q} Y_{ijmq} \geq \underline{f}_{ijm} \sum_{\substack{mm\in M,\\ q\in Q}} Y_{ijmmq} \qquad \forall (i,j) \in A, m \in M, \underline{f}_{ijm} > 0 \qquad \text{(D2)}$$

$$\sum_{q\in Q} Y_{ijmq} \leq \overline{f}_{ijm} \sum_{\substack{mm\in M,\\ q\in Q}} Y_{ijmmq} \qquad \forall (i,j) \in A, m \in M, \overline{f}_{ijm} < 1 \qquad \text{(D3)}$$

$$0 \leq \sum_{q\in N} Y_{ijmq} \leq u_{ijm} \qquad \forall (i,j) \in A, m \in M \qquad \text{(D4)}$$

$$\sum_{\substack{(i,n)\in A, m\in M,\\ q\in N}} Y_{inmq} \leq cap_n \qquad \forall n \in N \qquad \text{(D5)}$$

$$\sum_{\substack{(n,j)\in A, m\in M,\\ q\in N}} Y_{njmq} \leq cap_n \qquad \forall n \in N \qquad \text{(D6)}$$

$$0 \leq W_{qn} \qquad \forall q \in N, n \in N \qquad \text{(D7)}$$

<u>Discussion</u>

Given an interdiction $\hat{X}$, this problem solves for the optimal container flows Y (on each arc) along with any dropped container traffic W. The objective (D0) assesses the total cost of container movement in days, including a cost penalty for each interdicted arc that delays flow there, and a penalty cost (in days) for any dropped demand. Each constraint (D1) enforces conservation of flow at node n for traffic destined for node q. Each constraint (D2) limits the minimum fraction of flow on a particular arc using a particular mode, while each (D3) limits the maximum fraction. Each constraint (D4) limits non-negative container flow on an arc for some a mode. Each constraint (D5) limits the inbound traffic to a node, and each (D6) limits outbound traffic from each node. (D7) specifies non-negative dropped flows.

The primary input data for this model are the container demands, b_{nq}, the costs of traversing each segment by mode, c_{ijm}, and the capacities of the road or rail segments in each arc, u_{ijm}. The parameter wc_{nq} is the "penalty cost" associated with a container being directly shipped from its origin n to its destination q instead of traveling to its destination via truck or rail because the system does not have the capacity to allow it to get there, which is signaled when it is too costly for the container to do so.

In the original operator's problem, no node and therefore no arc is interdicted: $\hat{X}_{ij} = 0, \forall (i, j) \in A$. In the absence of interdiction, the operator may use any of the roads or rail lines to convey container traffic. The minimum-cost solution for a single week's TEU demand incurs 11,703,835 days of transit cost (14.72 transit days per TEU) and there is no dropped flow or penalty.

We can think of container flow for each O-D pair as a different commodity that competes for network resources (here, ship, road, and rail capacity). The size of such multi-commodity flow problems can be large, because the number of O-D pairs grows quadratically with the number of cities, and the number of potential paths for each commodity grows exponentially in the size of the network. For this case study, the operator's problem has 144 nodes, 3,640 arcs, and 3,253 commodities, yielding a grand total of just over 28 thousand constraints and 835 thousand variables. Demands total just over 795,300 TEU containers, each of which may follow a different route. Despite its size, we can solve this multi-commodity flow problem easily—using commercial optimization software, we can build and solve this operator's problem in a few seconds.

C. THE ATTACKER'S PROBLEM

To identify the worst-case disruption to an infrastructure, we consider the perspective of an intelligent adversary who can mount one or more simultaneous attacks on infrastructure components (here, the nodes in the network). We assume that these attacks are binary (i.e., no partial attacks) and that the attacker is limited by a maximum number of such attacks. We build a detailed mathematical program for determining the most disruptive attacks; the resulting two-sided (Attacker-Defender) optimization is stated as **ATTACKER:**

<u>Additional data</u> [units]

$\hat{\boldsymbol{Y}}$ container flows [TEUs]

$\hat{\boldsymbol{W}}$ dropped container flows [TEUs]

$\widehat{\boldsymbol{wcW}}$ total cost of dropped demand: $\sum_{q \in N, n \in N} wc_{qn} \hat{W}_{qn}$ [TEU days]

$\overline{attacks}$ maximum number of node attacks [cardinality]

<u>Additional decision variables</u> [units]

Q_n 1 if node n attacked, 0 otherwise [binary]

X_{ij} 1 if arc $(i, j) \in A$ interdicted, 0 otherwise [binary]

Formulation **ATTACKER**:

$$Z^* = \max_{Q,X} \min_{Y,W} \left(\sum_{\substack{(i,j)\in A,\\ m\in M, q\in Q}} Y_{ijmq}\,(c_{ijm} + q_{ij} X_{ij}) + \sum_{\substack{n\in N,\\ q\in N}} wc_{nq} W_{nq} \right) \qquad \text{(A0)}$$

s.t. (D1) – (D7) and

$$\sum_{n\in N} Q_n \le \overline{attacks} \qquad \text{(A1)}$$

$$X_{ij} \le Q_i + Q_j \qquad \forall (i,j)\in A \qquad \text{(A2)}$$

$$Q_n \in \{0,1\} \qquad \forall n \in N \qquad \text{(A3)}$$

$$X_{ij} \in \{0,1\} \qquad \forall (i,j)\in A \qquad \text{(A4)}$$

The objective (A0) measures the total transit cost (in TEU days, including penalty delays for traversing "interdicted" arcs) and the total penalty delays for "dropped" flow. Constraint (A1) limits the number of nodes that can be attacked. Constraints (A2) determine which arcs are interdicted by node attacks. Stipulations (A3-A4) define variable domains. This formulation conforms to the structure found in Brown et al. (2006) and cannot be solved with conventional optimization methods. We could also enumerate all possible attacks, and solve the resulting restricted linear programs, but this is impractical for problems of any reasonable size. For example, enumerating all possible 3-node attacks generates $\binom{144}{3}$ = 487,344 attack plans, each of which requires solving for the operator's best response.

D. SOLVING THE INTERMODAL MODEL VIA DECOMPOSITION

For any single, fixed set of operator flows, $\hat{\boldsymbol{Y}}$, and the resulting dropped demands, $\hat{\boldsymbol{W}}$, the attacker's optimal objective value, $Z_{\max}$, is bounded as follows:

$$Z_{\max} \le \sum_{\substack{q\in N,\\ (i,j)\in R}} \left[\hat{Y}_{ijq}(c_{ij} + q_{ij} X_{ij}) \right] + \widehat{\boldsymbol{wcW}} \qquad \text{(A5)}$$

We decompose **ATTACKER** by replacing inequality (A5) with a set of constraints (A5D), one for each observed flow $\hat{\boldsymbol{Y}}$.

New index

$k \in K$ decomposition iteration

New Data

$\hat{\boldsymbol{Y}}^k : \hat{Y}_{ijq}^k = \sum_{m \in M} Y_{ijmq}$, $\widehat{\boldsymbol{wcW}}^k = \sum_{q \in N, n \in N} wc_{qn} W_{qn}$, operator plans for iteration *k*, and total dropped demand costs.

Formulation **ATTACKER**$(\hat{\boldsymbol{Y}}, \widehat{\boldsymbol{wcW}})$

$$Z_{\max}(\hat{\boldsymbol{Y}}, \widehat{\boldsymbol{wcW}}) = \max_{Q,X} Z \tag{A0D}$$

s.t. (A1-A4)

$$Z \leq \sum_{\substack{(i,j) \in q, \\ q \in N}} \left[\hat{Y}_{ijq}^k (c_{ij} + q_{ij} X_{ij}) \right] + \widehat{\boldsymbol{wcW}}^k \qquad k = 1, \ldots, K \tag{A3D}$$

Call any solution $\boldsymbol{X}$ satisfying constraints (A1) and (A2) “admissible.”

The complete decomposition algorithm is as follows:

Algorithm DECOMPOSITION

Input: Data for attacker's problem, relative optimality tolerance $\rho \geq 0$;

Output: ρ-optimal interdiction plan $\mathbf{X}^*$, and responding defender plan $\mathbf{Y}^*$;

1. Initialize best lower bound $Z_{LB} \leftarrow -\infty$, best upper bound $Z_{UB} \leftarrow +\infty$, define the incumbent, null attack plan $\hat{\mathbf{X}}^1 \leftarrow \mathbf{0}$ as the best found so far, and set iteration counter $K \leftarrow 1$;
2. **Subproblem**: Solve subproblem **OPERATOR**$(\hat{\mathbf{X}}^K)$ to determine the optimal operator's responding transportation plan $\hat{\mathbf{Y}}^K$ given attack plan $\hat{\mathbf{X}}^K$; the bound on the associated objective is $Z_{\min}(\hat{\mathbf{X}}^K)$;
3. If K=1 and $\hat{\mathbf{X}}^1$ not admissible, go to step (6) (**Master Problem**);
4. If $Z_{LB} < Z_{\min}(\hat{\mathbf{X}}^K)$ set $Z_{LB} \leftarrow \bar{Z}_{\min}(\hat{\mathbf{X}}^K)$ and record improved incumbent attack plan $\mathbf{X}^* \leftarrow \hat{\mathbf{X}}^K$, and responding defender plan $\mathbf{Y}^* \leftarrow \hat{\mathbf{Y}}^K$;
5. If $(\left|Z_{UB} - Z_{LB}\right| / \max(10^{-9}, \left|Z_{LB}\right|) \leq \rho$) go to **End**;
6. Master Problem: Given defender plans $\hat{\mathbf{Y}}^k$, k=1,…K, attempt to solve master problem **ATTACKER**$(\hat{\mathbf{Y}})$ to determine an optimal attacker plan $\hat{\mathbf{X}}^{K+1}$. The bound on the associated objective is $Z_{\max}(\hat{\mathbf{Y}})$
7. If $Z_{UB} > Z_{\max}(\hat{\mathbf{Y}})$ set $Z_{UB} \leftarrow Z_{\max}(\hat{\mathbf{Y}})$;
8. If $(\left|Z_{UB} - Z_{LB}\right| / \max(10^{-9}, \left|Z_{LB}\right|) \leq \rho$) go to **End**;
9. Set $K \leftarrow K + 1$ and go to step (2) (**Subproblem)**;
10. **End**: Print, "$\mathbf{X}^*$ is an ρ-optimal attack plan, and $\mathbf{Y}^*$ is the operator response to that plan," and halt.

For the sake of efficiency, one need not store incumbent operation plans $\mathbf{Y}^*$ in step 4. These can quickly be recovered after-the-fact by solving **OPERATOR**$(\mathbf{X}^*)$.

In our test cases, we use a maximum of 30 iterations and relative convergence tolerance $\rho = 0.01$.

IV. SCENARIO AND RESULTS

A. BASELINE MODEL–NORMAL OPERATIONS

The primary purpose of our model is to provide a capability to assess the economic impacts on import and export container flows of various types of disruptions to ports or to the U.S. domestic transportation system (rail or truck). These costs are what decision makers will consider when deciding which infrastructure components to defend or fortify in order to protect the value of the system. To illustrate this capability, five types of possible disruptions are considered. These five examples are certainly not exhaustive of the model's capabilities, but they illustrate types of analyses the model will support.

1. Scenario

We first model the U.S. container transportation system with one week of import and export demand to establish the baseline costs to which we may compare abnormal scenarios. The baseline model represents the 46 foreign seaports, 14 seaports and 84 Transportation Analysis Zones introduced in Chapter II. Specific O-D pair demands are located in Appendix A (imports) and Appendix B (exports).

2. Results

Under normal conditions, the total cost of transporting one week of import and export demand (795,306 TEUs) is 11,786,605 TEU-days of transit cost or 14.82 transit days per TEU. While we cannot fully illustrate the individual routes followed between each Origin-Destination (O-D) pair under normal operations, we do show a sample detailing the demand, commodity flows and total costs for imports destined for Albany, NY. Table 6 shows the import demand data for the Albany, NY TAZ. Table 7 displays the routes (arcs by mode) chosen by the operator to meet the demand destined for Albany, NY TAZ.

Origin	Destination	2007 Demand (TEU/week)
BELGIUM	Albany, NY	37
BRAZIL	Albany, NY	80
CHINA MAINLAND	Albany, NY	765
CHINA TAIWAN	Albany, NY	76
FRANCE	Albany, NY	38
GERMANY	Albany, NY	98
HONG KONG	Albany, NY	146
INDIA	Albany, NY	49
INDONESIA	Albany, NY	38
ITALY	Albany, NY	91
JAPAN	Albany, NY	95
MALAYSIA	Albany, NY	37
NETHERLANDS	Albany, NY	47
SOUTH KOREA	Albany, NY	65
THAILAND	Albany, NY	55
UNITED KINGDOM	Albany, NY	41

Table 6. Import demand data for Albany, NY TAZ.

From	To	Mode	Flow (TEUs)	Arc Cost (Days)	Total Cost (TEU-days)
BELGIUM	NorfolkPort	Ship	37	8	296
BRAZIL	NorfolkPort	Ship	80	11	880
FRANCE	NorfolkPort	Ship	38	7	266
GERMANY	NorfolkPort	Ship	98	8	784
INDIA	NorfolkPort	Ship	49	19	931
NETHERLANDS	NorfolkPort	Ship	47	8	376
NorfolkPort	AlbanyNY	Truck	286	1	143
NorfolkPort	AlbanyNY	Rail	63	3	157
ITALY	NYNJPort	Ship	91	9	819
UNITEDKINGDOM	NYNJPort	Ship	41	7	287
NYNJPort	AlbanyNY	Rail	132	2	198
INDONESIA	OaklandPort	Ship	38	16	608
OaklandPort	AlbanyNY	Truck	31	6	187
OaklandPort	AlbanyNY	Rail	7	8	55
CHINAMNLND	SeaTacPort	Ship	765	11	8415
CHINATAIWAN	SeaTacPort	Ship	76	12	912
HONGKONG	SeaTacPort	Ship	146	12	1752
JAPAN	SeaTacPort	Ship	95	9	855
MALAYSIA	SeaTacPort	Ship	37	15	555
SOUTHKOREA	SeaTacPort	Ship	65	10	650
THAILAND	SeaTacPort	Ship	55	15	825
SeaTacPort	AlbanyNY	Truck	1016	6	6096
SeaTacPort	AlbanyNY	Rail	223	8	1784

Table 7. Operator plans these minimum-cost TEU flows to Albany, NY.

Under normal conditions, in which containers bound for U.S. destinations select the port from the least expensive path to a TAZ, ports exhibit relatively low utilization indicative of sufficient capacity, shown in Table 8. "TEUs (Imports and Exports)" in Table 8 is the number of TEUs the model chooses to send through each port to meet demand at minimum cost and "Percent of Total TEUs" is the TEUs handled by each port as a percentage of the 795,306 TEUs shipped in the model. "TEU Port Handling Capacity" is the sum of the individual terminal capacities and average TEUs handled by each port in 2007. Chapter II derives these capacities. "Percent of TEU Port Handling Capacity" is the number of TEUs handled divided by each port's TEU handling capacity.

Port	TEUs (Imports and Exports)	Percent of Total TEUs	TEU Port Handling Capacity	Percent of TEU Port Handling Capacity
Baltimore	27,371	3.44%	120,678	22.68%
Charleston	15,805	1.99%	93,713	16.87%
Houston	20,178	2.54%	35,355	57.07%
Jacksonville	7,369	0.93%	53,300	13.83%
Lazaro Cardenas, MX	301	0.04%	14,000	2.15%
Los Angeles/Long Beach	270,870	34.06%	455,434	59.48%
New York/New Jersey	55,062	6.92%	206,889	26.61%
Norfolk	54,217	6.82%	54,902	98.75%
Oakland	110,079	13.84%	116,006	94.89%
Prince Rupert, BC	5,060	0.64%	17,808	28.41%
Savannah	3,215	0.40%	102,770	3.13%
Seattle/Tacoma	160,314	20.16%	160,314	100.00%
South Florida	14,316	1.80%	95,470	15.00%
Vancouver, BC	51,149	6.43%	51,149	100.00%

Table 8. Baseline case showing optimal number of TEUs handled and percent of TEU port handling capacity of domestic ports when handling one week of TEU demand. For example, Baltimore handles 27,371 TEUs, which is 3.44% of total demand and 22.68% of its 120,678 TEU handling capacity.

B. SOUTHERN CALIFORNIA EARTHQUAKE

1. Scenario

The United States Geological Survey (USGS) recently released a report ("The ShakeOut Scenario") assessing the impacts of a postulated 7.8 magnitude earthquake along the San Andreas Fault in the Los Angeles area (Jones, et al., 2008). Among many conclusions regarding the impact of such an earthquake on the infrastructure in the Los Angeles area, the report estimates that while the port facilities in Los Angeles and Long

Beach would likely sustain only minor damage, the ports are likely to be closed for a period ranging from two weeks to two months as a result of damage to the highway, rail and pipeline facilities that connect them to the surrounding region and the nation at large. We represent this scenario by forcing the ports of Los Angeles and Long Beach closed. The remaining 13 ports remain operational.

LA-LB is the primary gateway to the U.S. for containerized cargo from Asia. More than 84% of all containers imported through LA-LB originate in eight countries, as shown below in Figure 9 (Port of Long Beach, 2007).

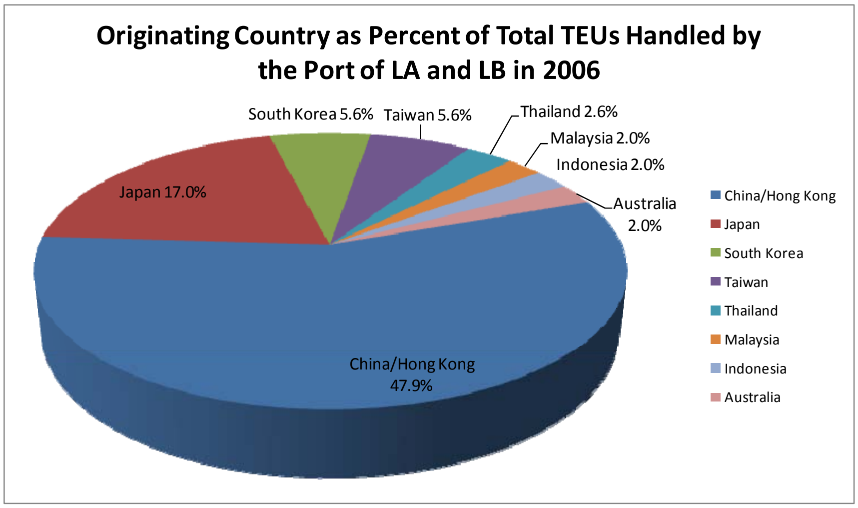

Figure 9. Originating container country as a percent of total TEUs handled by the Ports of Los Angeles and Long Beach (After: Port of Long Beach, 2007).

Over 70% of this cargo is destined for points outside of Southern California (Orange County Transportation Authority, 2009). For imports moving by rail or truck to destinations further east, other Pacific Coast ports (including ports in Canada and Mexico) are viable alternatives.

2. Results

The purpose of this scenario is to assess the impacts to other ports during a TSI, in this case a 7.8 magnitude earthquake, where the ports of Los Angeles and Long Beach (LA-LB) close for a period of two weeks.

After closing down the port of LA-LB, the model uses the other Pacific Coast ports to deliver the TEUs to the U.S. Table 9 shows operator plans directing TEUs after LA-LB is shutdown. Several ports, including the remaining operational ports in the Pacific (Prince Rupert, Vancouver, SeaTac, Oakland, and Lazaro Cardenas) and some on the Atlantic coast (Houston and New York-New Jersey), are now handling 100% of their TEUs capacity. The "Percentage Increase" by the each port is in comparison to the result from the baseline model, as shown in Table 8. Although not to full TEU capacity, the remaining ports also show a significant increase in TEU traffic. Surprisingly, loss of LA-LB leads to Baltimore, Charleston, Jacksonville and South Florida increasing throughputs by 59%, 33%, 29% and 62%, respectively.

Port	TEUs Handled (LA-LB closed)	Percent of Port TEU Handling Capacity (LA-LB closed)	Percent of Port TEU Handling Capacity (Baseline)	Percentage Increase in Port Usage (LA-LB closed)
Baltimore	98,916	81.97%	22.68%	59.29%
Charleston	47,031	50.19%	16.87%	33.32%
Houston	35,355	100.00%	57.07%	42.93%
Jacksonville	22,877	42.92%	13.83%	29.10%
Lazaro Cardenas, MX	14,000	100.00%	2.15%	97.85%
Los Angeles/Long Beach	-	0.00%	59.48%	-59.48%
New York/New Jersey	84,342	40.77%	26.61%	14.15%
Norfolk	54,902	100.00%	98.75%	1.25%
Oakland	116,006	100.00%	94.89%	5.11%
Prince Rupert, BC	17,808	100.00%	28.41%	71.59%
Savannah	17,918	17.44%	3.13%	14.31%
Seattle/Tacoma	160,314	100.00%	100.00%	0.00%
South Florida	74,209	77.73%	15.00%	62.73%
Vancouver, BC	51,149	100.00%	100.00%	0.00%

Table 9. Operator plans for port usage after LA-LB is shutdown. For example, Oakland handles 116,006 TEUs or 100% of its TEU handling capacity. With LA-LB open, Oakland handles 94.89% of its capacity. The closure of LA-LB increases Oakland's port capacity usage by 5.11%.

Our model calculates the total days of transit cost from origin to destination the demand (795,306 TEUs) requires. As illustrated in Figure 10, the closure of LA-LB increases transit costs by 14.75%. This translates to an increase of just over 2 days per TEU from 14.82 days per TEU to 17 days per TEU.

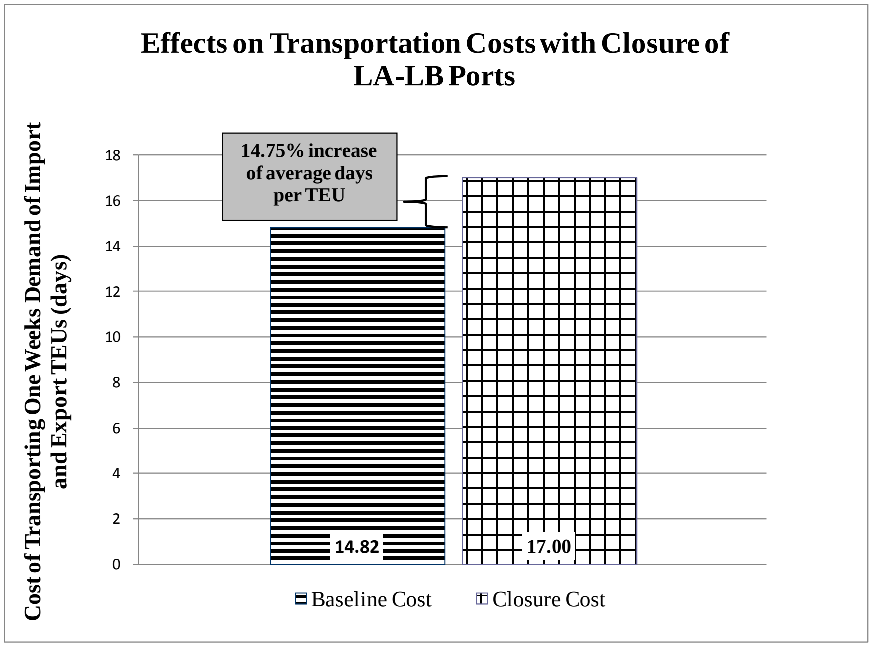

Figure 10. Additional transportation costs due to closure of ports of LA-LB for 14 days.

This shows how a 14-day closure of the ports at Los Angeles and Long Beach creates waves through the freight transportation system that are felt not only at other U.S. Pacific Coast ports, but also at East Coast ports. In addition, this event would affect the U.S. rail and truck industries, the ports in Canada and Mexico, as well as vessel owners and shipping lines, who would have to re-orient their operations over the period of recovery. The large increase in use of Atlantic Coast ports for traffic from Asian origins means a substantial increase in vessel traffic through the Panama Canal creating congestion and delays.

C. LOCKOUT BY THE INTERNATIONAL LONGSHOREMEN AND WAREHOUSEMEN'S UNION (ILWU)

1. Scenario

In September 2002, the Pacific Maritime Association Board of Directors, representing 72 ocean cargo carriers, terminal operators, and stevedoring companies of the West Coast shipping industry, locked longshoremen, dockworkers, and marine clerks out of terminals in retaliation for an intentional slowdown of labor by the ILWU (Pacific Maritime Association, 2002). The lockout closed West Coast seaports from San Diego to the Canadian border. We represent this scenario by closing the U.S. West Coast ports while the three West Coast non-U.S. ports remain operational (Vancouver, Prince Rupert, and Lazaro Cardenas).

2. Results

Our analysis reveals that shutting down the ports of LA-LB, Oakland, and SeaTac for 14 days will increase transportation costs dramatically. Table 10 shows the schedule of worst-case closures and resulting additional transportation days to deliver all 795,306 TEUs.

Number of Port Closures	Ports Closed	Resulting cost (days)	Increase (days)	Transportation cost (days/TEU)
0	No attacks (baseline)	11,786,605	n/a	14.82
1	LALB Port	13,524,784	1,738,179	17.01
2	LALB Port and SeaTac Port	15,170,491	1,645,707	19.08
3	LALB Port, Oakland Port and SeaTac Port	16,963,772	1,793,281	21.33

Table 10. Schedule of worst-case closures of U.S. West Coast ports and their consequences. For example, closing LA-LB, Oakland, and Seattle-Tacoma will cost 16,963,772 days to transport all TEUs to their destination, an increase of 1,793,281 days over the worst-case 2-node closure of LA-LB and Seattle-Tacoma. The closure results in an average cost of 21.33 days per TEU, an increase of 6.51 days over the baseline cost of 14.82 days.

We observe that the worst-case 1-node shutdown is the Port of Los Angeles-Long Beach. That is, losing this port is more costly to the system than the loss of any of the other two options. The optimal 2-node shutdown closes the ports of Los Angeles-Long Beach and Seattle-Tacoma. The worst-case 3-node shutdowns are the ports of Los Angeles-Long Beach, Oakland and Seattle-Tacoma. The two- and three-node shutdowns are monotonic, in the sense that each includes all the nodes shut down previously, plus one additional node.

The total cost of shutting down the ports LA-LB, Oakland and Seattle-Tacoma by the ILWU Board of Directors for 14 days would increase total shipping costs by an additional 5,177,167 days or as Figure 11 illustrates, the lockout results in an additional 6.5 days of delays per TEU. An increase of 43.92% in transportation costs from 14.82 to 21.33 shipping days per TEU.

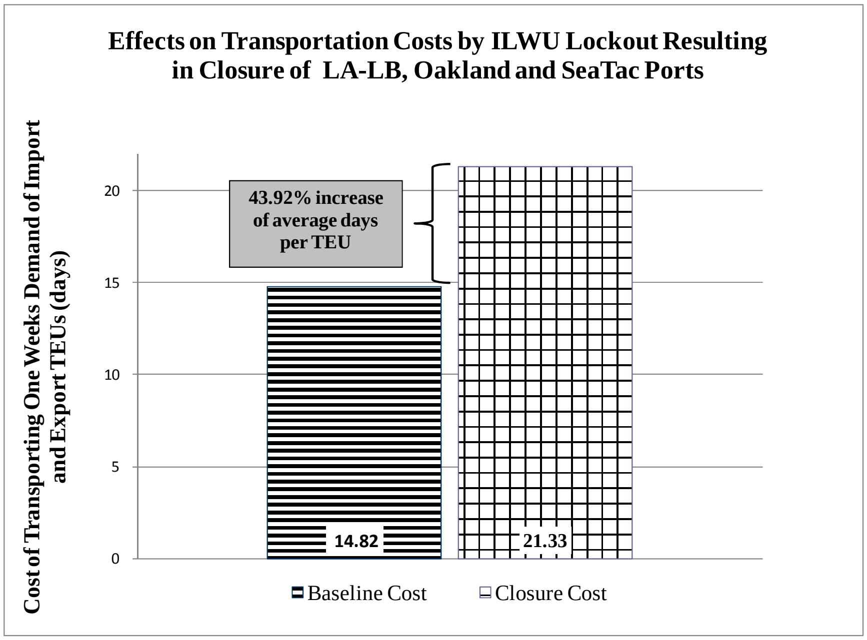

Figure 11. Additional transportation costs due to ILWU lockout for 14 days.

A closure of this magnitude will affect many other ports. As shown in Table 11, all the other ports in the model, with the exception of New York-New Jersey, will be working at 100% capacity. Although not at capacity, the port of New York-New Jersey increases TEU throughput by 45.23% over the baseline number of TEUs handled. While we cannot fully demonstrate the individual transportation costs the model calculates to determine the minimum transportation cost routes in this scenario, we can see that the port of New York-New Jersey is the port, in this model, furthest for Asian markets, which are the major trading partners of the West Coast ports. This might explain the reason all East Coast ports are at capacity, while New Yorkï New Jersey is the only port with remaining available capacity.

Port	TEUs Handled (ILWU Lockout)	Percent of Port TEU Handling Capacity (ILWU Lockout)	Percent of Port TEU Handling Capacity (Baseline)	Percentage Increase in Port Usage (ILWU Lockout)
Baltimore	120,678	100.00%	22.68%	77.32%
Charleston	93,713	100.00%	16.87%	83.13%
Houston	35,355	100.00%	57.07%	42.93%
Jacksonville	53,300	100.00%	13.83%	86.17%
Lazaro Cardenas, MX	14,000	100.00%	2.15%	97.85%
Los Angeles/Long Beach	-	0.00%	59.48%	-59.48%
New York/New Jersey	148,635	71.84%	26.61%	45.23%
Norfolk	54,902	100.00%	98.75%	1.25%
Oakland	2,382	2.05%	94.89%	-92.84%
Prince Rupert, BC	17,808	100.00%	28.41%	71.59%
Savannah	102,770	100.00%	3.13%	96.87%
Seattle/Tacoma	5,144	3.21%	100.00%	-96.79%
South Florida	95,470	100.00%	15.00%	85.00%
Vancouver, BC	51,149	100.00%	100.00%	0.00%

Table 11. Resulting TEU port flows during the ILWU lockout. For example, Charleston handles 93,713 TEUs during the lockout, which pushes it to 83.13% above its normal usage. It is handling 100% of its capacity vice 16.87% it normally handles.

Although closed during the ILWU lockout, the ports of Oakland and Seattle-Tacoma handle 2,382 and 5,144 TEUs, respectively. After a disruption in the transportation network, in this case the lockout, our model allows the operator to decide the least costly solution to the multi-commodity flow transportation problem. In this case, the operator finds it less expensive to let these small numbers of TEUs be frustrated in route for 14 days than to re-route them through other ports (i.e., New Yorkï New Jersey).

In this scenario, Oakland handles both import and export TEUs while Seattle-Tacoma only handles exports. Table 12 illustrates the origin-destination pairs and mode of transportation of the 2,382 import and export TEUs handled by Oakland during the ILWU lockout. Table 13 illustrates the origin-destination pairs and mode of transportation of the 5,144 export TEUs handled by Seattle-Tacoma during the same period.

Origin	Destination	Tansportation Mode to Port of Oakland	TEUs
HONGKONG	BillingsMT	Ship	99
CHINAMNLND	BoiseCityID	Ship	1432
CHINATAIWAN	BoiseCityID	Ship	142
HONGKONG	BoiseCityID	Ship	260
JAPAN	BoiseCityID	Ship	196
SOUTHKOREA	BoiseCityID	Ship	125
DallasTX	ELSALVADOR	Rail	9
DallasTX	ELSALVADOR	Truck	43
BillingsMT	HONGKONG	Rail	14
BillingsMT	HONGKONG	Truck	62
		Total TEUs	2382

Table 12. Origin-Destination pairs of TEUs handled by port of Oakland despite its 14-day ILWU lockout.

Origin	Destination	Transportation Mode to Port of Seattle/Tacoma	TEUs
PhoenixAZ	CHINAMNLND	Truck	2819
PhoenixAZ	CHINAMNLND	Rail	926
PhoenixAZ	CHINATAIWAN	Truck	294
PhoenixAZ	HONGKONG	Truck	412
PhoenixAZ	JAPAN	Truck	420
PhoenixAZ	SOUTHKOREA	Truck	273
		Total TEUs	5144

Table 13. Origin-Destination pairs of TEUs handled by port of Seattle-Tacoma despite its 14-day ILWU lockout.

D. HURRICANE CLOSES THE PORTS OF SAVANNAH, GA AND CHARLESTON, SC

1. Scenario

The 14-modeled ports serve a vital role in international commerce, managing over 90 percent of total containerized traffic entering or leaving the U.S. (American Association of Port Authorities, 2009). A direct hit by a hurricane on one of these seaports could cripple its home state's economic engines and have a ripple effect across the country.

We present this scenario as another capability of this model with multiple simultaneous disruptions, in this case by a hurricane. The hurricane affects the approximately 90 miles of coastline between the ports of Savannah, GA and Charleston, SC and consequently forces them closed.

2. Results

The purpose of this scenario is to assess the impacts to other ports during a hurricane that closes the ports of Savannah, GA and Charleston, SC. The total transportation cost due to the hurricane is 11,791,678 transportation days. This reveals an increase of 5,073 days or 0.64% in costs over the baseline model. Figure 12 illustrates the small difference in average days per TEU as other ports in the area can absorb the containers normally handled by these two ports.

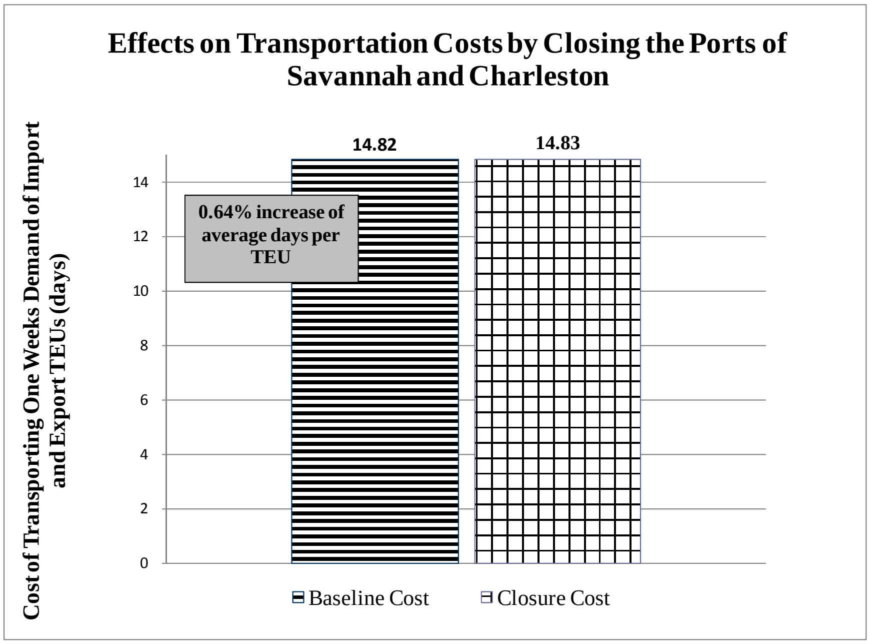

Figure 12. Additional transportation costs due to a 14-day closure of the Ports of Savannah, GA and Charleston, SC.

In the baseline model, Savannah and Charleston handle 19,020 (2.44%) of the 795,306 TEUs in the model. After the hurricane shuts down the two ports, the operator must decide the optimal network flow that will minimize the total transportation costs. As shown in Table 14, the operator plans to shift the TEUs to the ports of Baltimore, Houston, Jacksonville, and South Florida. Oakland now handles 1.33% more of its capacity where 1,522 come from LA-LB and 20 come from an East Coast port.

Port	TEUs Handled (Charleston and Savannah closed)	Percent of Port TEU Handling Capacity (Charleston and Savannah closed)	Percent of Port TEU Handling Capacity (Baseline)	Difference in TEUs Handled (Charleston and Savannah closed minus Baseline)	Percentage Increase in Port Usage (Charleston and Savannah closed)
Baltimore	38,357	31.78%	22.68%	10,985	9.10%
Charleston	-	0.00%	16.87%	(15,805)	-16.87%
Houston	20,447	57.83%	57.07%	269	0.76%
Jacksonville	12,347	23.17%	13.83%	4,978	9.34%
Los Angeles/Long Beach	269,348	59.14%	59.48%	(1,522)	-0.33%
Lazaro Cardenas, MX	301	2.15%	2.15%	-	0.00%
New York/New Jersey	54,902	26.54%	26.61%	(160)	-0.08%
Norfolk	54,410	99.10%	98.75%	194	0.35%
Oakland	111,621	96.22%	94.89%	1,542	1.33%
Prince Rupert, BC	5,060	28.41%	28.41%	-	0.00%
Savannah	-	0.00%	3.13%	(3,215)	-3.13%
Seattle/Tacoma	160,314	100.00%	100.00%	-	0.00%
South Florida	17,050	17.86%	15.00%	2,734	2.86%
Vancouver, BC	51,149	100.00%	100.00%	-	0.00%

Table 14. Operator plans when a hurricane shuts down the ports of Savannah and Charleston. For example, Jacksonville handles 12,347 TEUs during the lockout, which is 9.34% above its normal capacity usage. With the additional 4,978 TEUs, it is handling 23.17% of its capacity vice the 13.83% it normally handles.

E. REDUCED CAPACITY AT PORT OF OAKLAND DUE TO INCREASED SECURITY MEASURES

1. Scenario

Increased security measures have the potential to reduce a port’s import processing rate, and thereby decrease the port’s capacity, affecting exports and increasing delays for shippers. Container inspections are carried out either while containers are waiting in the container yard for pick-up or after loading on trucks or trains for departure from the port (Deparment of Homeland Security, 2006). This is, at least in part, an effort to minimize the impact on port processing and prevent additional delays. However, increasingly stringent efforts at inspection and prevention of contraband material from entering the U.S. will result in decreases in the TEU processing rate of ports. In this case, we have postulated a 30-percent decrease in the rate at which vessels are unloaded at the dock due to increased inspections before containers are allowed out of the container yard and into the U.S. The reduced capacity is limited to the Port of Oakland to see the diversions of container traffic that occur as a direct result of the reduced capacity.

2. Results

Our results reveal diversions of imports from Asia through Los Angeles and Long Beach as well as some East Coast. This is a direct result of both Seattle-Tacoma and Vancouver already operating at capacity in the baseline case. Although the Panama Canal capacity is not reflected in our model, these diversions will increase flow through the Panama Canal and potentially cause an additional bottleneck.

The total transportation cost due to a reduced capacity in Oakland is 11,791,678 transportation days, an increase of 4,211 days or 0.53% in costs over the baseline model. Figure 13 illustrates the small difference in average days per TEU as other regional ports can absorb the additional container traffic normally handled by Oakland.

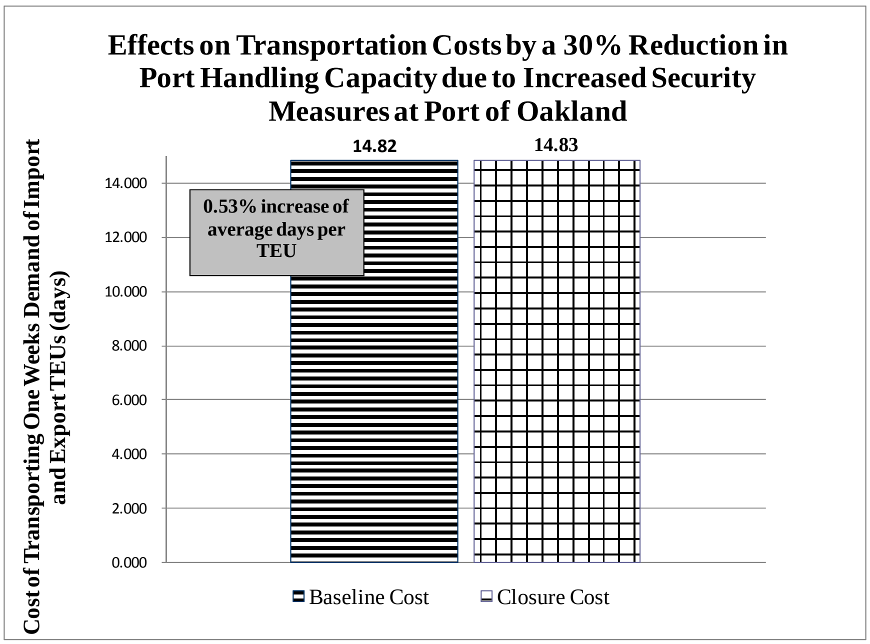

Figure 13. Additional transportation costs due to increased security measures at the Port of Oakland.

Table 15 summarizes the flow through the ports as they compare to the baseline results (Table 8). The major increase in traffic is at Los Angeles and Long Beach, which handles an additional 28,184 TEUs; the majority of the 28,875 TEUs Oakland cannot handle. The port of Prince Rupert absorbs 493 of the remaining TEUs previously handled by Oakland while the remaining 198 TEUs ship via East Coast ports.

Port	TEUs Handled (Oakland Reduced Capacity)	Percent of TEU Port Handling Capacity (Oakland Reduced Capacity)	Percent of TEU Port Handling Capacity (Baseline)	Change in TEUs Handled (Reduced Capacity-Baseline)	Change in Percentage of TEU Port Handling Capacity
Baltimore	26,048	21.58%	22.68%	-1,324	-1.10%
Charleston	17,943	19.15%	16.87%	2,138	2.28%
Houston	19,690	55.69%	57.07%	-488	-1.38%
Jacksonville	6,947	13.03%	13.83%	-422	-0.80%
Lazaro Cardenas, MX	301	2.15%	2.15%	0	0.00%
Los Angeles/Long Beach	299,054	65.66%	59.48%	28,184	6.18%
New York/New Jersey	53,904	26.05%	26.61%	-1,158	-0.56%
Norfolk	54,902	100.00%	98.75%	685	1.25%
Oakland	81,204	100.00%	94.89%	-28,875	5.11%
Prince Rupert, BC	5,553	31.18%	28.41%	493	2.77%
Savannah	3,468	3.37%	3.13%	253	0.24%
Seattle/Tacoma	160,314	100.00%	100.00%	0	0.00%
South Florida	14,830	15.53%	15.00%	513	0.53%
Vancouver, BC	51,149	100.00%	100.00%	0	0.00%

Table 15. Operator plans in response to a 30% capacity reduction in the port of Oakland. For example, LA-LB handles 299,054 TEUs, an increase of 28,184 TEUs over the baseline. This translates to a 6.18% increase over normal TEU handling levels; a total of 65.66% of its total TEU handling capacity.

The reduced capacity at Oakland (81,204 TEUs/week) is completely used, as is the available capacity at Vancouver. The result of a 30% reduction in the port of Oakland directly increases the traffic on many ports, an increase that many will not be able to support. The results of similar policies implemented at other ports without first expanding capacity will be at a much higher cost.

F. AN INTELLIGENT TERRORIST ATTACKS THE UNITED STATES CONTAINER INTERMODAL TRANSPORTATION SYSTEM

1. Scenario

Our model allows us to close or “attack” a port or TAZ and this causes incident arcs, highway or rail lines, to be “interdicted.” An intelligent terrorist, with enough resources, can also deliver an attack on the same components of the container transportation system. The key piece of intelligence is where an intelligent terrorist will strike. In order to get an insight into the most desirable targets to an intelligent terrorist we allow the model to attack either port or TAZ nodes.

2. Results

Our findings reveal the impact of an attack that results in the shutdown of any port or TAZ centroid city where all incident arcs are "interdicted." Our model provides a way to extract the impact as the incremental transportation costs (days) associated with a TSI modeled as an attack on single or multiple nodes (ports or TAZs).

We present our results in Table 16. The optimal 1-node attack is the port of Los Angeles and Long Beach. This is not unexpected as LA-LB has the most capacity and thus has the potential for the most disruption in TEU traffic flow throughout the transportation system. As shown in Table 16, the average increase in cost from no attacks to one attack is 2.19 days/TEU but when two attacks occur, we only get an increase of 2.07 days/TEU over the one-attack costs. This is the best the attacker, or "terrorist," can do with two-attacks. This is where the convergence tolerance (ρ) of 1%, in step 8 of the DECOMPOSITION algorithm, is met.

Number of attacks	Nodes attacked	Total Cost (days)	Increase in Total Cost (days)	Transportation cost (days/TEU)	Additional Transportation cost (days/TEU)
0	No attacks (baseline)	11,786,605	n/a	14.82	n/a
1	Los Angeles and Long Beach Port	13,524,784	1,738,179	17.01	2.19
2	Optimal 1-node attack and SeaTac Port	15,174,532	1,649,748	19.08	2.07
3	Optimal 2-node attack and Oakland Port	16,964,985	1,790,453	21.33	2.25
4	Optimal 3-node attack and NY-NJ Port	18,595,900	1,630,915	23.38	2.05
5	Optimal 4-node attack and Baltimore Port	21,085,230	2,489,330	26.51	3.13

Table 16. Schedule of worst-case attacks on U.S. container transportation system and resultant transportation costs. For example, with four nodes attacked (Ports of LA-LB, SeaTac, Oakland and NY-NJ) the total cost is 18,595,900 days. This is an increase of 1,630,915 days, or 2.05 days/TEU, over the worst-case 3-node attack, for a total of 23.38 days/TEU.

Although LA-LB is the top choice of an intelligent terrorist, the model does consider other options. Table 17 illustrates the other top choices and resultant transportation costs for a 1-node attack plan. We observe that that the second-best 1-

node attack plan is not a port at all but the New York Transportation Analysis Zone. In fact, all other best 1-node attacks are TAZs.

Worst-case 1-node attacks	Total Cost (days)	Increase in Total Cost over Baseline (days)	Transportation cost (days/TEU)
No attacks (baseline)	11,786,605	n/a	14.82
Los Angeles and Long Beach Port	13,524,784	1,738,179	17.01
NewYork, NY TAZ	13,106,244	1,319,639	16.48
Los Angeles, CA TAZ	12,650,674	864,069	15.91
San Jose, CA TAZ	12,273,278	486,673	15.43
Chicago, IL TAZ	12,306,201	519,596	15.47

Table 17. Worst-case 1-node attack plans on the commercial container transportation system. For example, the fifth worst-case 1-node attack would be on the Chicago, IL Transportation Analysis Zone because it would result in a transportation cost increase of 519,596 days over the baseline cost. The total cost is 12,306,201 which translates to an average of 15.47 transit days per TEU.

We show the change from baseline conditions in TEU port handling capacity by each port with a 4-node optimal attack in Table 18. After a 4-node worst-case attack every unaffected port is at 100% capacity in order to handle the 795,306 TEUs of demand in the model. The operator finds the optimal solution is to "wait out" the four-port (LA-LB, New York-New Jersey, Seattle-Tacoma, and Oakland) closure and pay the additional transportation penalty cost of 14 days per TEU because it has no available capacity anywhere else. In a sense, the 596,325 TEUs are stopped in the closed ports and become "frustrated cargo" while they wait for disposition instructions from the operator. The operator then ships the TEUs when the four ports re-open.

Port	TEUs Handled (4-attacks)	TEUs Handled (Baseline)	Change in TEUs Handled (4-attacks)	Percent of Total TEUs (4-attacks)	Percent of TEU Port Handling Capacity (4-attacks)
Baltimore	120,678	27,371	93,307	11.72%	100.00%
Charleston	93,713	15,805	77,908	9.78%	100.00%
Houston	35,355	20,178	15,177	1.91%	100.00%
Jacksonville	53,300	7,369	45,931	5.77%	100.00%
Lazaro Cardenas, MX	14,000	301	13,699	1.72%	100.00%
Los Angeles/Long Beach	65,242	270,870	(205,628)	-25.82%	14.33%
New York/New Jersey	994	55,062	(54,068)	-6.79%	0.48%
Norfolk	54,902	54,217	685	0.09%	100.00%
Oakland	90,919	110,079	(19,160)	-2.41%	78.37%
Prince Rupert, BC	17,808	5,060	12,748	1.60%	100.00%
Savannah	102,770	3,215	99,555	12.50%	100.00%
Seattle/Tacoma	-	160,314	(160,314)	-20.13%	0.00%
South Florida	95,470	14,316	81,154	10.19%	100.00%
Vancouver, BC	51,149	51,149	-	0.00%	100.00%

Table 18. Percent change in TEU port-handling capacity with a worst-case 4-node attack on ports and Transportation Analysis Zones vulnerable to attack. For example, the port of LA-LB handles 270,870 TEUs in the baseline model. With LA-LB, NY-NJ, Oakland, and Seattle-Tacoma shutdown, the operator delays 65,242 TEUs, or 14.33% of its handling capacity, until LA-LB reopens. This is a 205,628 TEU, or 25.82%, reduction in TEUs handled by LA-LB.

The model gives us the five worst-case 1-node, 2-node, 3-node, 4-node, and 5-node attack plans. The model also gives the second through fifth best attacks but we are only considering worst-case scenarios as the suboptimal attacks would only benefit the operator for the reason that they are less costly (days). Table 19 summarizes these attack plans and Figure 14 displays their resulting costs and increases over baseline costs.

Maximum Number of Attacks	Node Attacked	Node Attacked	Node Attacked	Node Attacked	Node Attacked	Transit Cost (days)	Delay Penalty (days)	Total Transportation Cost (days)	Days/TEU
0						11,786,605	-	11,786,605	14.82
1	**LALBPort**					**13,524,784**	**-**	**13,524,784**	**17.01**
1	NewYorkNY					11,789,698	1,316,546	13,106,244	16.48
1	LosAngelesCA					11,794,728	855,946	12,650,674	15.91
1	SanJoseCA					12,016,602	256,676	12,273,278	15.43
1	ChicagoIL					11,786,605	519,596	12,306,201	15.47
2	**LALBPort**	**SeaTacPort**				**15,174,532**	**-**	**15,174,532**	**19.08**
2	NewYorkNY	LALBPort				13,531,935	1,331,946	14,863,881	18.69
2	LALBPort	OaklandPort				14,722,125	-	14,722,125	18.51
2	LosAngelesCA	LALBPort				13,532,416	881,146	14,413,562	18.12
2	LALBPort	VancouverBCPort				13,997,619	-	13,997,619	17.6
3	**LALBPort**	**OaklandPort**	**SeaTacPort**			**16,932,365**	**32,620**	**16,964,985**	**21.33**
3	NewYorkNY	LALBPort	SeaTacPort			15,179,036	1,344,546	16,523,582	20.78
3	LALBPort	SeaTacPort	VancouverBCPort			15,774,368	167,832	15,942,200	20.05
3	LosAngelesCA	LALBPort	SeaTacPort			15,180,319	881,146	16,061,465	20.2
3	NewYorkNY	LALBPort	OaklandPort			14,731,328	1,152,746	15,884,074	19.97
4	**LALBPort**	**NYNJPort**	**OaklandPort**	**SeaTacPort**		**14,896,246**	**3,699,654**	**18,595,900**	**23.38**
4	LALBPort	OaklandPort	SeaTacPort	VancouverBCPort		17,327,161	520,562	17,847,723	22.44
4	NewYorkNY	LALBPort	OaklandPort	SeaTacPort		16,799,507	1,488,004	18,287,511	22.99
4	BaltimorePort	LALBPort	OaklandPort	SeaTacPort		16,384,289	979,300	17,363,589	21.83
4	BaltimorePort	LALBPort	NYNJPort	SeaTacPort		14,183,413	3,153,220	17,336,633	21.8
5	**BaltimorePort**	**LALBPort**	**NYNJPort**	**OaklandPort**	**SeaTacPort**	**13,639,428**	**7,445,802**	**21,085,230**	**26.51**
5	LALBPort	NYNJPort	OaklandPort	SeaTacPort	SouthFloridaPort	14,564,946	5,057,346	19,622,292	24.67
5	LALBPort	NYNJPort	OaklandPort	SavannahPort	SeaTacPort	14,075,332	6,611,234	20,686,566	26.01
5	JacksonvillePort	LALBPort	NYNJPort	OaklandPort	SeaTacPort	14,766,711	4,610,942	19,377,653	24.37
5	BaltimorePort	LALBPort	NYNJPort	SavannahPort	SeaTacPort	12,811,530	7,047,432	19,858,962	24.97

Table 19. Summary of total transportation costs by a given number of maximum attacks and the second through fifth best attack for each maximum number of attacks. For example, the worst-case 5-node attack plan includes Ports of Baltimore, Los Angeles-Long Beach, New York-New Jersey, Oakland and Seattle-Tacoma. The total transportation cost will be 21,085,230 transportation days or 26.51 days/TEU. The total cost is composed of a transit cost of 13,639,428 days and an additional 7,445,802 days in delay incurred by utilizing closed facilities.

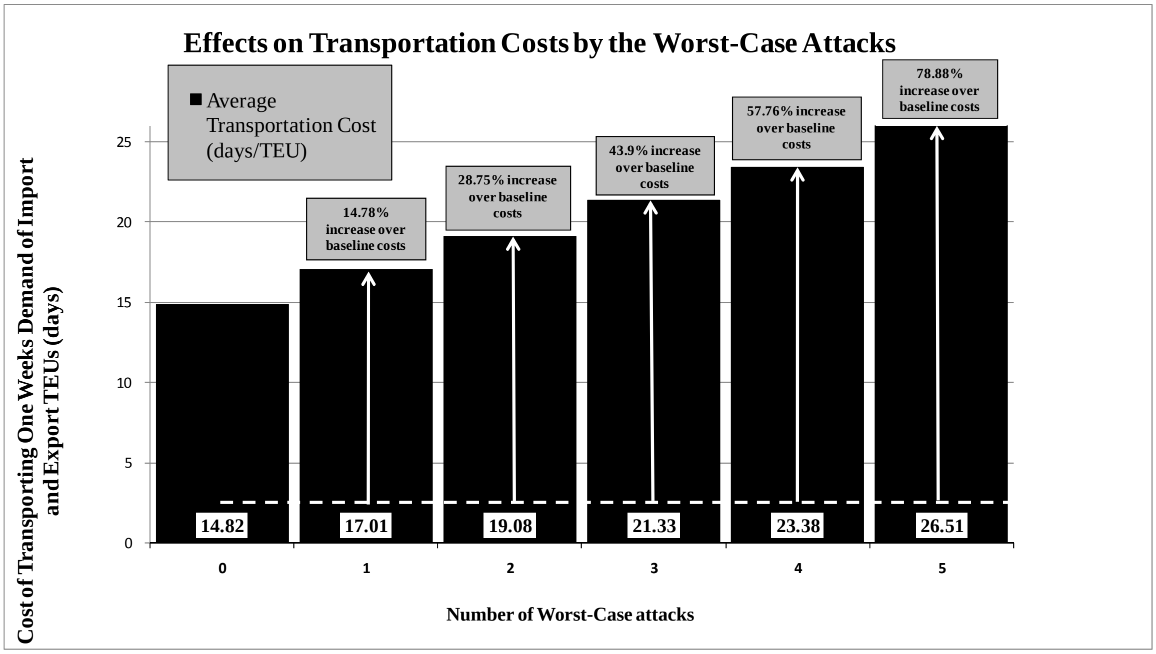

Figure 14. Additional transportation costs per worst-case attack.

V. CONCLUSIONS AND FUTURE RESEARCH

A. CONCLUSIONS

International containerized freight movement is a vital part of the supply chain for many companies, and a critical element of moving consumer goods to destinations within the U.S. Containerized imports also present a clear security concern. The potential for terrorists to ship dirty bombs, chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized and is a main concern of the Department of Homeland Security.

The purpose of this thesis is to create a modeling tool for looking at container flows and the potential changes in those flows under a variety of conditions including port disruptions by extensive security-related delays, natural disasters, union work stoppages, and terrorist actions. This effort has included a careful examination of available data on container movements, development of a network model to represent container movements both internationally and domestically and an estimation of those parameters that build a representative global transportation network.

The model represents the major supply chain links serving manufacturers and consumers in the U.S., as well as export flow patterns for U.S. shippers serving worldwide markets. The global network model represents flows of containerized freight between origins and destinations, where one or the other is outside the U.S. An import container movement, for example, will follow a path through the network that involves a seaborne movement from a foreign origin port to a U.S. port of entry, a processing movement at the U.S. port, and then an overland movement by either truck or rail to its destination in the U.S. A basic premise of the model is that path "choices" an operator makes in this network are based on total transportation costs (days) required to reach a destination. Ports and access to destinations via truck and rail are subject to capacity limits. Reduced capacity (or complete unavailability) of some facilities (ports, rail and highways connections) in such a model also result in adjustment of the flow patterns and increase overall transportation costs. The delays of flows and changes in costs inflicted by an attack are the prime drivers of economic impacts.

We chose to use the Attacker-Defender model to operate our transportation network. The Attacker-Defender model is a two-stage model that finds the best defense plan by finding the best attack. The model allows the attacker to first attack the network, and then the defender alters flow on the network to optimize the flow of container TEUs on the attacked network. Using this model the decision maker can defend the nodes that correspond to the worst-case attack.

We have implemented the model, showed how to employ this model, and analyzed five situations that represent real-world TEU traffic flow disruptions. We conclude that West Coast seaports are key components in the container transportation system. The three West Coast ports modeled that represent five West Coast ports are in reality potential targets to a terrorist. We determine the West Coast has sufficient infrastructure in place to accommodate increased security measures and reducing the the Port of Oakland's port handling capacity by 30%. Similarly, the East Coast has sufficient infrastructure to support the re-routed TEUs in case a hurricane shuts down the ports of Savannah, GA and Charleston for 14 days. Conversely, there is insufficient West Coast infrastructure to accommodate an event, like a 7.8 magnitude earthquake, incapacitating the ports of Los Angeles and Long Beach beyond a two-week period. Such an event would render a strain not only on the West Coast ports but also on several East Coast ports that now have to handle the TEUs normally handled by the ports of Los Angeles and Long Beach, resulting with incremental transportation costs to ocean carriers of over 1.7 million transportation days. We find a labor union dispute the most significant threat to the vitality of the West Coast container transportation system. We find a 14-day dispute increases the overall transportation cost by over 43% and fully occupies the the East Coast port's TEU handling capacity with the exception of the ports of New York and New Jersey. Lastly, we determine the five optimal attacks an intelligent terrorist might employ to maximize the cost on the U.S. economy. Although we include three foreign ports in our model, all five plans include only domestic U.S. ports. The five optimal target ports for a terrorist are Los Angeles and Long Beach, Oakland, Seattle and Tacoma, Baltimore and New York and New Jersey.

One limitation of our research is that we assume the operator can re-route TEUs individually (in a TEU flow model), even though in reality these are loaded on discrete ships, and the entire ship would have to be re-routed. For the scenarios we examine, there are enough ships that we do not anticipate this restriction to introduce too much distortion. The total number of TEUs handled in our model requires 160 Panamax class ships, each of which can hold 5,000 TEUs; according to Container Insight (2007), there are over 230 Panamax ships in service.

B. FUTURE RESEARCH

This representation of the internal United States container transportation system includes what we believe is a minimal level of realism for the function of this system—demand for TEUs between foreign ports, domestic ports and TAZ pairs; as well as better detailed highway and rail capacities. One way to do this is by incorporating more detailed or sophisticated representations with, for example, a higher fidelity rail network or more realistic highway-travel route patterns and congestion as influenced and directed by experts of intermodal planning and transportation systems.

Additions to the model might also include the research and analysis of additional commodities to include strategic and domestic commodities and cargoes (e.g., bulk, break-bulk, and petroleum).

In this model, we obtain optimal operator response plans. To create effective contingency plans, however, the scope of the TSI impacts must be understood, and the wide range of stakeholders—shippers, international shipping lines, port authorities and terminal operators, rail carriers, trucking companies, etc.—must be engaged, so that the freight system responds to the disruption as a system, rather than as uncoordinated reactions from its various parts. To accomplish this is a significant challenge.

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APPENDIX A: ESTIMATED ORIGIN DESTINATION TABLE FOR U.S. IMPORTS

ARGENTINA	
BostonMA	65
NewYorkNY	218
PhiladelphiaPA	54
BaltimoreMD	80
AtlantaGA	47
MiamiFL	36
DetroitMI	41
ChicagoIL	73
HoustonTX	45
DallasTX	52
SanJoseCA	58
AUSTRALIA	
LosAngelesCA	95
BostonMA	69
NewYorkNY	231
PhiladelphiaPA	58
BaltimoreMD	88
AtlantaGA	56
MiamiFL	38
DetroitMI	54
ChicagoIL	100
MinneapolisMN	45
HoustonTX	63
DallasTX	77
DenverCO	49
PhoenixAZ	45
SeattleWA	52
PortlandOR	37
SanJoseCA	133
AUSTRIA	
LosAngelesCA	205
SanDiegoCA	37
BostonMA	62
NewYorkNY	196
PhiladelphiaPA	45
BaltimoreMD	66
AtlantaGA	34
DetroitMI	34
ChicagoIL	56
LosAngelesCA	55
BostonMA	58
BANGLADESH	
NewYorkNY	191
PhiladelphiaPA	47
BaltimoreMD	70
AtlantaGA	38
DetroitMI	38
ChicagoIL	66
HoustonTX	38
BELGIUM	
DallasTX	47
SeattleWA	34
SanJoseCA	78
LosAngelesCA	118
BostonMA	231
AlbanyNY	37
NewYorkNY	752
PittsburghPA	58
HarrisburgPA	36
PhiladelphiaPA	177
BaltimoreMD	256
NorfolkVA	34
RaleighNC	47
CharlotteNC	41

BELGIUM	
AtlantaGA	129
JacksonvilleFL	47
OrlandoFL	54
MiamiFL	92
TampaFL	59
BirminghamAL	52
NashvilleTN	41
MemphisTN	38
LouisvilleKY	34
ClevelandOH	77
ColumbusOH	41
CincinnatiOH	38
DetroitMI	129
GrandRapidsMI	36
IndianapolisIN	59
ChicagoIL	214
MilwaukeeWI	54
MinneapolisMN	91
KansasCityMO	44
StLouisMO	65
NewOrleansLA	56
HoustonTX	113
DallasTX	126
DenverCO	73
PhoenixAZ	54
SeattleWA	54
PortlandOR	37
SanJoseCA	124
LosAngelesCA	205
SanDiegoCA	37
BRAZIL	
PortlandME	55
BostonMA	495
AlbanyNY	80
SyracuseNY	66
RochesterNY	59
BuffaloNY	70
NewYorkNY	1708
PittsburghPA	136
HarrisburgPA	81
PhiladelphiaPA	419
BaltimoreMD	613
CharlestonWV	76
RichmondVA	78
NorfolkVA	88
RaleighNC	120
GreensboroNC	73
CharlotteNC	110
GreenvilleSC	87
ColumbiaSC	66
AtlantaGA	383
JacksonvilleFL	153
OrlandoFL	172
MiamiFL	297
TampaFL	191
MobileAL	69
BirminghamAL	162
KnoxvilleTN	58
NashvilleTN	118
MemphisTN	110
LouisvilleKY	89
LexingtonKY	51
ClevelandOH	177
ColumbusOH	95

BRAZIL	
CincinnatiOH	96
DaytonOH	43
ToledoOH	44
DetroitMI	284
GrandRapidsMI	80
FortWayneIN	59
IndianapolisIN	143
ChicagoIL	499
MilwaukeeWI	125
GreenBayWI	51
MinneapolisMN	209
DesMoinesIA	71
KansasCityMO	110
StLouisMO	165
LittleRockAR	51
JacksonMS	48
NewOrleansLA	177
HoustonTX	341
AustinTX	76
DallasTX	375
SanAntonioTX	78
CorpusChristiTX	36
ElPasoTX	52
OklahomaCityOK	73
TulsaOK	71
WichitaKS	36
OmahaNE	66
DenverCO	190
AlbuquerqueNM	40
PhoenixAZ	144
LasVegasNV	67
SaltLakeCityUT	63
BoiseCityID	47
SeattleWA	122
PortlandOR	84
SanJoseCA	320
SacramentoCA	63
LosAngelesCA	548
SanDiegoCA	100
CHILE	
BostonMA	135
NewYorkNY	480
PittsburghPA	44
PhiladelphiaPA	122
BaltimoreMD	184
RaleighNC	38
CharlotteNC	37
AtlantaGA	136
JacksonvilleFL	48
OrlandoFL	59
MiamiFL	98
TampaFL	69
BirminghamAL	59
NashvilleTN	45
MemphisTN	45
LouisvilleKY	34
ClevelandOH	62
ColumbusOH	36
CincinnatiOH	36
DetroitMI	106
IndianapolisIN	58
ChicagoIL	203
MilwaukeeWI	51
MinneapolisMN	84

CHILE	
KansasCityMO	45
StLouisMO	69
NewOrleansLA	73
HoustonTX	144
DallasTX	158
DenverCO	82
PhoenixAZ	65
LasVegasNV	36
SeattleWA	62
PortlandOR	44
SanJoseCA	174
SacramentoCA	34
LosAngelesCA	297
CHINA MAINLAND	
SanDiegoCA	56
PortlandME	510
BostonMA	4636
AlbanyNY	765
SyracuseNY	672
RochesterNY	613
BuffaloNY	761
NewYorkNY	15803
PittsburghPA	1449
HarrisburgPA	804
PhiladelphiaPA	3927
BaltimoreMD	5966
CharlestonWV	756
RichmondVA	728
NorfolkVA	785
GreenvilleNC	286
WilmingtonNC	293
RaleighNC	1095
GreensboroNC	686
CharlotteNC	1025
GreenvilleSC	802
ColumbiaSC	587
CharlestonSC	250
AtlantaGA	3539
SavannahGA	264
JacksonvilleFL	1260
OrlandoFL	1474
MiamiFL	2424
TampaFL	1657
MobileAL	684
BirminghamAL	1517
ChattanoogaTN	298
KnoxvilleTN	569
NashvilleTN	1281
MemphisTN	1209
LouisvilleKY	1026
LexingtonKY	562
ClevelandOH	2061
ColumbusOH	1149
CincinnatiOH	1105
DaytonOH	507
LouisvilleKY	1026
LexingtonKY	562
ClevelandOH	2061
ColumbusOH	1149
CincinnatiOH	1105
DaytonOH	507
ToledoOH	548
DetroitMI	3634
GrandRapidsMI	1048

CHINA MAINLAND	
FortWayneIN	753
IndianapolisIN	1790
ChicagoIL	6849
MilwaukeeWI	1805
GreenBayWI	758
DuluthMN	151
MinneapolisMN	3311
DesMoinesIA	1079
KansasCityMO	1581
StLouisMO	2097
SpringfieldMO	403
LittleRockAR	606
JacksonMS	507
NewOrleansLA	1859
HoustonTX	4001
AustinTX	925
DallasTX	4851
SanAntonioTX	1007
CorpusChristiTX	444
ElPasoTX	819
OklahomaCityOK	1081
TulsaOK	941
WichitaKS	558
OmahaNE	1109
SiouxFallsSD	411
FargoND	449
BillingsMT	541
DenverCO	3510
AlbuquerqueNM	698
PhoenixAZ	2935
LasVegasNV	1787
SaltLakeCityUT	1595
BoiseCityID	1432
SeattleWA	4131
PortlandOR	2832
SanJoseCA	9141
ReddingCA	168
SacramentoCA	1793
FresnoCA	757
LosAngelesCA	13243
SanDiegoCA	2408
PortlandME	49
BostonMA	456
AlbanyNY	76
CHINA TAIWAN	
SyracuseNY	66
RochesterNY	60
BuffaloNY	74
NewYorkNY	1554
PittsburghPA	143
HarrisburgPA	80
PhiladelphiaPA	386
BaltimoreMD	587
CharlestonWV	74
RichmondVA	71
NorfolkVA	77
RaleighNC	107
GreensboroNC	67
CharlotteNC	100
GreenvilleSC	78
ColumbiaSC	58
AtlantaGA	348
JacksonvilleFL	124
OrlandoFL	146

CHINA TAIWAN	
GreensboroNC	67
CharlotteNC	100
GreenvilleSC	78
ColumbiaSC	58
AtlantaGA	348
JacksonvilleFL	124
OrlandoFL	146
MiamiFL	239
TampaFL	163
MobileAL	67
BirminghamAL	150
KnoxvilleTN	56
NashvilleTN	126
MemphisTN	120
LouisvilleKY	102
LexingtonKY	55
ClevelandOH	203
ColumbusOH	113
CincinnatiOH	109
DaytonOH	49
ToledoOH	54
DetroitMI	357
GrandRapidsMI	103
FortWayneIN	74
IndianapolisIN	176
ChicagoIL	673
MilwaukeeWI	177
GreenBayWI	74
MinneapolisMN	326
DesMoinesIA	106
KansasCityMO	155
StLouisMO	206
SpringfieldMO	40
LittleRockAR	59
JacksonMS	49
NewOrleansLA	183
HoustonTX	393
AustinTX	91
DallasTX	477
SanAntonioTX	99
CorpusChristiTX	44
ElPasoTX	81
OklahomaCityOK	106
TulsaOK	92
WichitaKS	55
OmahaNE	109
SiouxFallsSD	40
FargoND	44
BillingsMT	54
DenverCO	345
AlbuquerqueNM	69
PhoenixAZ	289
LasVegasNV	176
SaltLakeCityUT	157
BoiseCityID	142
SeattleWA	407
PortlandOR	279
SanJoseCA	899
SacramentoCA	176
FresnoCA	74
LosAngelesCA	1302
SanDiegoCA	236
COLOMBIA	
BostonMA	77
NewYorkNY	297

COLOMBIA	
PhiladelphiaPA	77
BaltimoreMD	111
AtlantaGA	88
JacksonvilleFL	40
OrlandoFL	41
MiamiFL	73
TampaFL	45
BirminghamAL	37
DetroitMI	48
ChicagoIL	88
MinneapolisMN	34
NewOrleansLA	40
HoustonTX	73
DallasTX	76
SanJoseCA	49
LosAngelesCA	87
COSTA RICA	
BostonMA	126
NewYorkNY	514
PittsburghPA	40
PhiladelphiaPA	136
BaltimoreMD	194
RaleighNC	44
CharlotteNC	44
GreenvilleSC	34
AtlantaGA	168
JacksonvilleFL	82
OrlandoFL	84
MiamiFL	148
TampaFL	88
BirminghamAL	69
NashvilleTN	41
MemphisTN	37
ClevelandOH	48
DetroitMI	77
IndianapolisIN	43
ChicagoIL	142
MilwaukeeWI	34
MinneapolisMN	55
StLouisMO	49
NewOrleansLA	70
HoustonTX	118
DallasTX	117
DenverCO	47
PhoenixAZ	34
SanJoseCA	67
LosAngelesCA	120
DENMARK	
BostonMA	55
NewYorkNY	176
PhiladelphiaPA	41
BaltimoreMD	59
ChicagoIL	51
LosAngelesCA	49
DOMINICAN REP	
BostonMA	76
NewYorkNY	297
PhiladelphiaPA	77
BaltimoreMD	109
AtlantaGA	78
JacksonvilleFL	37
OrlandoFL	37
MiamiFL	69
TampaFL	40
DetroitMI	41

DOMINICAN REP	
ChicagoIL	77
NewOrleansLA	34
HoustonTX	59
DallasTX	60
SanJoseCA	38
LosAngelesCA	69
ECUADOR	
BostonMA	69
NewYorkNY	251
PhiladelphiaPA	65
BaltimoreMD	98
AtlantaGA	77
MiamiFL	55
TampaFL	40
BirminghamAL	34
DetroitMI	55
ChicagoIL	109
MinneapolisMN	44
StLouisMO	38
NewOrleansLA	44
HoustonTX	84
DallasTX	89
DenverCO	44
SanJoseCA	89
LosAngelesCA	154
EL SALVADOR	
NewYorkNY	118
BaltimoreMD	45
AtlantaGA	37
ChicagoIL	52
HoustonTX	40
DallasTX	43
SanJoseCA	65
LosAngelesCA	117
FINLAND	
BostonMA	38
NewYorkNY	122
BaltimoreMD	43
ChicagoIL	37
LosAngelesCA	37
FRANCE	
BostonMA	240
AlbanyNY	38
NewYorkNY	782
PittsburghPA	59
HarrisburgPA	36
PhiladelphiaPA	184
BaltimoreMD	264
NorfolkVA	36
RaleighNC	48
CharlotteNC	43
AtlantaGA	133
JacksonvilleFL	48
OrlandoFL	55
MiamiFL	95
TampaFL	60
BirminghamAL	54
NashvilleTN	43
MemphisTN	38
LouisvilleKY	36
ClevelandOH	80
ColumbusOH	43
CincinnatiOH	40
DetroitMI	133
GrandRapidsMI	37

FRANCE	
IndianapolisIN	62
ChicagoIL	221
MilwaukeeWI	56
MinneapolisMN	93
KansasCityMO	45
StLouisMO	66
NewOrleansLA	58
HoustonTX	115
DallasTX	129
DenverCO	74
PhoenixAZ	54
SeattleWA	55
PortlandOR	37
SanJoseCA	126
LosAngelesCA	207
SanDiegoCA	38
GERMANY	
PortlandME	70
BostonMA	618
AlbanyNY	98
SyracuseNY	81
RochesterNY	69
BuffaloNY	81
NewYorkNY	1973
PittsburghPA	150
HarrisburgPA	91
PhiladelphiaPA	460
BaltimoreMD	666
CharlestonWV	80
RichmondVA	81
NorfolkVA	91
RaleighNC	122
GreensboroNC	74
CharlotteNC	107
GreenvilleSC	81
ColumbiaSC	60
AtlantaGA	339
JacksonvilleFL	122
OrlandoFL	140
MiamiFL	239
TampaFL	157
MobileAL	58
BirminghamAL	136
KnoxvilleTN	58
NashvilleTN	110
MemphisTN	100
LouisvilleKY	91
LexingtonKY	51
ClevelandOH	202
ColumbusOH	110
CincinnatiOH	102
DaytonOH	48
ToledoOH	52
DetroitMI	343
GrandRapidsMI	96
FortWayneIN	69
IndianapolisIN	158
ChicagoIL	572
MilwaukeeWI	144
GreenBayWI	59
MinneapolisMN	240
DesMoinesIA	82
KansasCityMO	117
StLouisMO	172
LittleRockAR	47

GERMANY	
JacksonMS	41
NewOrleansLA	150
HoustonTX	298
AustinTX	67
DallasTX	337
SanAntonioTX	70
ElPasoTX	48
OklahomaCityOK	70
TulsaOK	70
WichitaKS	37
OmahaNE	74
DenverCO	195
AlbuquerqueNM	38
PhoenixAZ	142
LasVegasNV	73
SaltLakeCityUT	69
BoiseCityID	54
SeattleWA	146
PortlandOR	100
SanJoseCA	335
SacramentoCA	66
LosAngelesCA	548
SanDiegoCA	100
GUATEMALA	
BostonMA	107
NewYorkNY	390
PittsburghPA	36
PhiladelphiaPA	100
BaltimoreMD	151
AtlantaGA	121
JacksonvilleFL	43
OrlandoFL	52
MiamiFL	85
TampaFL	62
BirminghamAL	54
NashvilleTN	40
MemphisTN	40
ClevelandOH	51
DetroitMI	87
IndianapolisIN	48
ChicagoIL	169
MilwaukeeWI	41
MinneapolisMN	69
KansasCityMO	37
StLouisMO	59
NewOrleansLA	67
HoustonTX	131
DallasTX	139
DenverCO	71
PhoenixAZ	80
LasVegasNV	45
SaltLakeCityUT	36
SeattleWA	70
PortlandOR	51
SanJoseCA	224
SacramentoCA	44
LosAngelesCA	407
SanDiegoCA	82
HONDURAS	
BostonMA	118
NewYorkNY	431
PittsburghPA	40
PhiladelphiaPA	111
BaltimoreMD	166
RaleighNC	36

HONDURAS	
CharlotteNC	34
AtlantaGA	133
JacksonvilleFL	48
OrlandoFL	58
MiamiFL	95
TampaFL	69
BirminghamAL	59
NashvilleTN	43
MemphisTN	44
ClevelandOH	56
DetroitMI	95
IndianapolisIN	54
ChicagoIL	187
MilwaukeeWI	45
MinneapolisMN	76
KansasCityMO	41
StLouisMO	65
NewOrleansLA	76
HoustonTX	143
DallasTX	153
DenverCO	78
PhoenixAZ	88
LasVegasNV	49
SaltLakeCityUT	40
SeattleWA	77
PortlandOR	56
SanJoseCA	247
SacramentoCA	48
LosAngelesCA	448
SanDiegoCA	91
HONG KONG	
PortlandME	98
BostonMA	881
AlbanyNY	146
SyracuseNY	128
RochesterNY	117
BuffaloNY	144
NewYorkNY	2995
PittsburghPA	275
HarrisburgPA	153
PhiladelphiaPA	743
BaltimoreMD	1131
CharlestonWV	143
RichmondVA	137
NorfolkVA	148
GreenvilleNC	54
WilmingtonNC	55
RaleighNC	207
GreensboroNC	131
CharlotteNC	194
GreenvilleSC	153
ColumbiaSC	111
CharlestonSC	47
AtlantaGA	666
SavannahGA	49
JacksonvilleFL	238
OrlandoFL	278
MiamiFL	460
TampaFL	315
MobileAL	128
BirminghamAL	286
ChattanoogaTN	56

HONG KONG	
KnoxvilleTN	107
NashvilleTN	242
MemphisTN	228
LouisvilleKY	194
LexingtonKY	106
ClevelandOH	389
ColumbusOH	217
CincinnatiOH	209
DaytonOH	96
ToledoOH	103
DetroitMI	686
GrandRapidsMI	198
FortWayneIN	142
IndianapolisIN	337
ChicagoIL	1282
MilwaukeeWI	339
GreenBayWI	142
MinneapolisMN	618
DesMoinesIA	202
KansasCityMO	297
StLouisMO	394
SpringfieldMO	76
LittleRockAR	114
JacksonMS	96
NewOrleansLA	349
HoustonTX	752
AustinTX	174
DallasTX	910
SanAntonioTX	190
CorpusChristiTX	82
ElPasoTX	151
OklahomaCityOK	202
TulsaOK	177
WichitaKS	104
OmahaNE	207
SiouxFallsSD	77
FargoND	84
BillingsMT	99
DenverCO	650
AlbuquerqueNM	129
PhoenixAZ	543
LasVegasNV	328
SaltLakeCityUT	293
BoiseCityID	260
SeattleWA	745
PortlandOR	511
SanJoseCA	1665
SacramentoCA	327
FresnoCA	139
LosAngelesCA	2430
SanDiegoCA	441
INDIA	
PortlandME	34
BostonMA	308
AlbanyNY	49
SyracuseNY	43
RochesterNY	37
BuffaloNY	45
NewYorkNY	1010
PittsburghPA	85
HarrisburgPA	49
PhiladelphiaPA	245

INDIA	
BaltimoreMD	365
CharlestonWV	45
RichmondVA	45
NorfolkVA	49
RaleighNC	69
GreensboroNC	43
CharlotteNC	62
GreenvilleSC	47
ColumbiaSC	36
AtlantaGA	199
JacksonvilleFL	71
OrlandoFL	84
MiamiFL	143
TampaFL	95
MobileAL	36
BirminghamAL	82
NashvilleTN	67
MemphisTN	63
LouisvilleKY	55
ClevelandOH	117
ColumbusOH	63
CincinnatiOH	60
DetroitMI	199
GrandRapidsMI	56
FortWayneIN	40
IndianapolisIN	93
ChicagoIL	342
MilwaukeeWI	88
GreenBayWI	36
MinneapolisMN	148
DesMoinesIA	51
KansasCityMO	74
StLouisMO	104
NewOrleansLA	93
HoustonTX	191
AustinTX	44
DallasTX	221
SanAntonioTX	47
OklahomaCityOK	47
TulsaOK	45
OmahaNE	48
DenverCO	133
PhoenixAZ	110
LasVegasNV	66
SaltLakeCityUT	58
BoiseCityID	49
SeattleWA	142
PortlandOR	98
SanJoseCA	327
SacramentoCA	65
LosAngelesCA	486
SanDiegoCA	88
INDONESIA	
BostonMA	232
AlbanyNY	38
BuffaloNY	37
NewYorkNY	779
PittsburghPA	71
HarrisburgPA	40
PhiladelphiaPA	192
BaltimoreMD	294
CharlestonWV	37

INDONESIA	
RichmondVA	36
NorfolkVA	38
RaleighNC	55
GreensboroNC	34
CharlotteNC	52
GreenvilleSC	40
AtlantaGA	176
JacksonvilleFL	63
OrlandoFL	74
MiamiFL	122
TampaFL	84
BirminghamAL	76
NashvilleTN	62
MemphisTN	60
LouisvilleKY	49
ClevelandOH	100
ColumbusOH	56
CincinnatiOH	54
DetroitMI	176
GrandRapidsMI	51
FortWayneIN	37
IndianapolisIN	87
ChicagoIL	328
MilwaukeeWI	87
GreenBayWI	36
MinneapolisMN	157
DesMoinesIA	51
KansasCityMO	76
StLouisMO	102
NewOrleansLA	91
HoustonTX	195
AustinTX	45
DallasTX	236
SanAntonioTX	49
ElPasoTX	38
OklahomaCityOK	52
TulsaOK	47
OmahaNE	52
DenverCO	162
PhoenixAZ	137
LasVegasNV	81
SaltLakeCityUT	71
BoiseCityID	62
SeattleWA	176
PortlandOR	122
SanJoseCA	411
SacramentoCA	81
FresnoCA	34
LosAngelesCA	610
SanDiegoCA	110
ISRAEL	
BostonMA	106
NewYorkNY	348
PhiladelphiaPA	84
BaltimoreMD	124
AtlantaGA	66
MiamiFL	47
ClevelandOH	38
DetroitMI	65
ChicagoIL	110
MinneapolisMN	47
HoustonTX	60

ISRAEL	
DallasTX	69
DenverCO	40
SanJoseCA	73
LosAngelesCA	120
ITALY	
PortlandME	65
BostonMA	570
AlbanyNY	91
SyracuseNY	76
RochesterNY	66
BuffaloNY	78
NewYorkNY	1844
PittsburghPA	146
HarrisburgPA	88
PhiladelphiaPA	441
BaltimoreMD	643
CharlestonWV	77
RichmondVA	80
NorfolkVA	88
RaleighNC	118
GreensboroNC	73
CharlotteNC	106
GreenvilleSC	80
ColumbiaSC	59
AtlantaGA	334
JacksonvilleFL	121
OrlandoFL	142
MiamiFL	238
TampaFL	157
MobileAL	58
BirminghamAL	135
KnoxvilleTN	56
NashvilleTN	109
MemphisTN	100
LouisvilleKY	89
LexingtonKY	51
ClevelandOH	198
ColumbusOH	106
CincinnatiOH	99
DaytonOH	47
ToledoOH	49
DetroitMI	332
GrandRapidsMI	93
FortWayneIN	66
IndianapolisIN	155
ChicagoIL	555
MilwaukeeWI	142
GreenBayWI	58
MinneapolisMN	238
DesMoinesIA	80
KansasCityMO	115
StLouisMO	169
LittleRockAR	47
JacksonMS	41
NewOrleansLA	151
HoustonTX	302
AustinTX	69
DallasTX	343
SanAntonioTX	71
ElPasoTX	49
OklahomaCityOK	70
TulsaOK	69

ITALY	
WichitaKS	37
OmahaNE	74
DenverCO	195
AlbuquerqueNM	40
PhoenixAZ	146
LasVegasNV	74
SaltLakeCityUT	70
BoiseCityID	54
SeattleWA	148
PortlandOR	102
SanJoseCA	342
SacramentoCA	67
LosAngelesCA	567
SanDiegoCA	103
JAPAN	
PortlandME	63
BostonMA	576
AlbanyNY	95
SyracuseNY	84
RochesterNY	77
BuffaloNY	96
NewYorkNY	1973
PittsburghPA	181
HarrisburgPA	100
PhiladelphiaPA	492
BaltimoreMD	745
CharlestonWV	95
RichmondVA	91
NorfolkVA	98
GreenvilleNC	36
WilmingtonNC	36
RaleighNC	136
GreensboroNC	85
CharlotteNC	128
GreenvilleSC	100
ColumbiaSC	73
AtlantaGA	444
JacksonvilleFL	158
OrlandoFL	184
MiamiFL	301
TampaFL	207
MobileAL	87
BirminghamAL	191
ChattanoogaTN	37
KnoxvilleTN	71
NashvilleTN	161
MemphisTN	153
LouisvilleKY	129
LexingtonKY	70
ClevelandOH	258
ColumbusOH	144
CincinnatiOH	139
DaytonOH	63
ToledoOH	69
DetroitMI	458
GrandRapidsMI	132
FortWayneIN	95
IndianapolisIN	225
ChicagoIL	870
MilwaukeeWI	229
GreenBayWI	96
MinneapolisMN	426
DesMoinesIA	137
KansasCityMO	202

JAPAN	
StLouisMO	265
SpringfieldMO	51
LittleRockAR	77
JacksonMS	65
NewOrleansLA	236
HoustonTX	510
AustinTX	118
DallasTX	620
SanAntonioTX	128
CorpusChristiTX	56
ElPasoTX	106
OklahomaCityOK	139
TulsaOK	120
WichitaKS	71
OmahaNE	143
SiouxFallsSD	54
FargoND	59
BillingsMT	73
DenverCO	459
AlbuquerqueNM	91
PhoenixAZ	385
LasVegasNV	239
SaltLakeCityUT	213
BoiseCityID	196
SeattleWA	573
PortlandOR	392
SanJoseCA	1238
SacramentoCA	243
FresnoCA	102
LosAngelesCA	1765
SanDiegoCA	321
MALAYSIA	
BostonMA	229
AlbanyNY	37
BuffaloNY	34
NewYorkNY	753
PittsburghPA	65
HarrisburgPA	37
PhiladelphiaPA	183
BaltimoreMD	273
CharlestonWV	34
NorfolkVA	37
RaleighNC	51
CharlotteNC	47
GreenvilleSC	36
AtlantaGA	157
JacksonvilleFL	56
OrlandoFL	66
MiamiFL	109
TampaFL	74
BirminghamAL	67
NashvilleTN	56
MemphisTN	54
LouisvilleKY	45
ClevelandOH	92
ColumbusOH	51
CincinnatiOH	49
DetroitMI	161
GrandRapidsMI	47
IndianapolisIN	78
ChicagoIL	298
MilwaukeeWI	78
MinneapolisMN	142
DesMoinesIA	47

MALAYSIA	
KansasCityMO	69
StLouisMO	92
NewOrleansLA	81
HoustonTX	174
AustinTX	40
DallasTX	210
SanAntonioTX	44
ElPasoTX	34
OklahomaCityOK	47
TulsaOK	41
OmahaNE	47
DenverCO	147
PhoenixAZ	122
LasVegasNV	73
SaltLakeCityUT	65
BoiseCityID	56
SeattleWA	159
PortlandOR	110
SanJoseCA	365
SacramentoCA	71
LosAngelesCA	541
SanDiegoCA	98
NETHERLANDS	
BostonMA	293
AlbanyNY	47
SyracuseNY	38
BuffaloNY	40
NewYorkNY	945
PittsburghPA	73
HarrisburgPA	44
PhiladelphiaPA	225
BaltimoreMD	324
CharlestonWV	38
RichmondVA	40
NorfolkVA	44
RaleighNC	59
GreensboroNC	36
CharlotteNC	52
GreenvilleSC	40
AtlantaGA	165
JacksonvilleFL	59
OrlandoFL	67
MiamiFL	115
TampaFL	76
BirminghamAL	66
NashvilleTN	54
MemphisTN	48
LouisvilleKY	44
ClevelandOH	99
ColumbusOH	52
CincinnatiOH	49
DetroitMI	165
GrandRapidsMI	45
IndianapolisIN	76
ChicagoIL	272
MilwaukeeWI	69
MinneapolisMN	115
DesMoinesIA	38
KansasCityMO	56
StLouisMO	82
NewOrleansLA	73
HoustonTX	143
DallasTX	162
SanAntonioTX	34

NETHERLANDS	
OklahomaCityOK	34
OmahaNE	36
DenverCO	93
PhoenixAZ	67
LasVegasNV	34
SeattleWA	69
PortlandOR	48
SanJoseCA	159
LosAngelesCA	260
SanDiegoCA	48
NEW ZEALAND	
BostonMA	56
NewYorkNY	192
PhiladelphiaPA	48
BaltimoreMD	73
AtlantaGA	47
DetroitMI	44
ChicagoIL	84
MinneapolisMN	37
HoustonTX	54
DallasTX	65
DenverCO	41
PhoenixAZ	40
SeattleWA	44
SanJoseCA	114
LosAngelesCA	179
PAKISTAN	
BostonMA	98
NewYorkNY	321
PhiladelphiaPA	77
BaltimoreMD	115
AtlantaGA	63
MiamiFL	45
ClevelandOH	37
DetroitMI	63
ChicagoIL	109
MinneapolisMN	47
HoustonTX	60
DallasTX	70
DenverCO	41
SeattleWA	37
SanJoseCA	87
LosAngelesCA	131
PERU	
NewYorkNY	103
BaltimoreMD	40
ChicagoIL	44
DallasTX	36
SanJoseCA	37
LosAngelesCA	63
PHILIPPINES	
BostonMA	113
NewYorkNY	382
PittsburghPA	36
PhiladelphiaPA	95
BaltimoreMD	144
AtlantaGA	87
OrlandoFL	36
MiamiFL	59
TampaFL	40
BirminghamAL	37
ClevelandOH	49
DetroitMI	88
IndianapolisIN	43

PHILIPPINES	
ChicagoIL	163
MilwaukeeWI	43
MinneapolisMN	78
KansasCityMO	37
StLouisMO	51
NewOrleansLA	45
HoustonTX	96
DallasTX	117
DenverCO	82
PhoenixAZ	70
LasVegasNV	41
SaltLakeCityUT	37
SeattleWA	93
PortlandOR	65
SanJoseCA	213
SacramentoCA	41
LosAngelesCA	312
SanDiegoCA	56
POLAND	
BostonMA	47
NewYorkNY	150
PhiladelphiaPA	36
BaltimoreMD	51
ChicagoIL	44
LosAngelesCA	43
PORTUGAL	
BostonMA	43
NewYorkNY	140
BaltimoreMD	47
ChicagoIL	38
LosAngelesCA	36
RUSSIA	
BostonMA	41
NewYorkNY	133
BaltimoreMD	45
ChicagoIL	40
LosAngelesCA	40
SINGAPORE	
BostonMA	63
NewYorkNY	210
PhiladelphiaPA	52
BaltimoreMD	80
AtlantaGA	47
DetroitMI	48
ChicagoIL	89
MinneapolisMN	43
HoustonTX	52
DallasTX	63
DenverCO	44
PhoenixAZ	37
SeattleWA	48
SanJoseCA	110
LosAngelesCA	163
SOUTH AFRICA	
BostonMA	69
NewYorkNY	228
PhiladelphiaPA	55
BaltimoreMD	84
AtlantaGA	48
MiamiFL	36
DetroitMI	44
ChicagoIL	76
HoustonTX	47
DallasTX	54

SOUTH AFRICA	
SanJoseCA	58
LosAngelesCA	95
SOUTH KOREA	
PortlandME	43
BostonMA	390
AlbanyNY	65
SyracuseNY	56
RochesterNY	52
BuffaloNY	65
NewYorkNY	1334
PittsburghPA	122
HarrisburgPA	67
PhiladelphiaPA	332
BaltimoreMD	504
CharlestonWV	63
RichmondVA	62
NorfolkVA	66
RaleighNC	92
GreensboroNC	58
CharlotteNC	87
GreenvilleSC	67
ColumbiaSC	49
AtlantaGA	298
JacksonvilleFL	106
OrlandoFL	124
MiamiFL	205
TampaFL	139
MobileAL	58
BirminghamAL	128
KnoxvilleTN	48
NashvilleTN	109
MemphisTN	103
LouisvilleKY	87
LexingtonKY	48
ClevelandOH	173
ColumbusOH	98
CincinnatiOH	93
DaytonOH	43
ToledoOH	47
DetroitMI	306
GrandRapidsMI	89
FortWayneIN	65
IndianapolisIN	153
ChicagoIL	580
MilwaukeeWI	153
GreenBayWI	65
MinneapolisMN	283
DesMoinesIA	92
KansasCityMO	135
StLouisMO	179
SpringfieldMO	34
LittleRockAR	51
JacksonMS	43
NewOrleansLA	157
HoustonTX	339
AustinTX	78
DallasTX	414
SanAntonioTX	85
CorpusChristiTX	37
ElPasoTX	70
OklahomaCityOK	92
TulsaOK	80
WichitaKS	48
OmahaNE	95
SiouxFallsSD	36
FargoND	38

SOUTH KOREA	
BillingsMT	47
DenverCO	302
AlbuquerqueNM	60
PhoenixAZ	251
LasVegasNV	155
SaltLakeCityUT	137
BoiseCityID	125
SeattleWA	363
PortlandOR	249
SanJoseCA	801
SacramentoCA	157
FresnoCA	66
LosAngelesCA	1151
SanDiegoCA	209
SPAIN	
BostonMA	202
NewYorkNY	655
PittsburghPA	49
PhiladelphiaPA	154
BaltimoreMD	220
RaleighNC	40
CharlotteNC	34
AtlantaGA	109
JacksonvilleFL	40
OrlandoFL	45
MiamiFL	78
TampaFL	51
BirminghamAL	43
NashvilleTN	34
ClevelandOH	66
ColumbusOH	34
DetroitMI	110
IndianapolisIN	51
ChicagoIL	180
MilwaukeeWI	45
MinneapolisMN	76
KansasCityMO	36
StLouisMO	54
NewOrleansLA	48
HoustonTX	95
DallasTX	106
DenverCO	59
PhoenixAZ	44
SeattleWA	44
SanJoseCA	100
LosAngelesCA	166
SRILANKA	
BostonMA	43
NewYorkNY	140
PhiladelphiaPA	34
BaltimoreMD	51
ChicagoIL	48
SanJoseCA	48
LosAngelesCA	73
SWEDEN	
BostonMA	92
NewYorkNY	294
PhiladelphiaPA	69
BaltimoreMD	99
AtlantaGA	51
MiamiFL	36
DetroitMI	52
ChicagoIL	85
MinneapolisMN	36
HoustonTX	45
DallasTX	51

SWEDEN	
SanJoseCA	51
LosAngelesCA	82
THAILAND	
PortlandME	37
BostonMA	332
AlbanyNY	55
SyracuseNY	48
RochesterNY	44
BuffaloNY	54
NewYorkNY	1127
PittsburghPA	103
HarrisburgPA	58
PhiladelphiaPA	279
BaltimoreMD	425
CharlestonWV	54
RichmondVA	52
NorfolkVA	56
RaleighNC	78
GreensboroNC	49
CharlotteNC	73
GreenvilleSC	58
ColumbiaSC	43
AtlantaGA	250
JacksonvilleFL	89
OrlandoFL	104
MiamiFL	173
TampaFL	118
MobileAL	48
BirminghamAL	107
KnoxvilleTN	41
NashvilleTN	91
MemphisTN	85
LouisvilleKY	73
LexingtonKY	40
ClevelandOH	146
ColumbusOH	81
CincinnatiOH	78
DaytonOH	36
ToledoOH	38
DetroitMI	256
GrandRapidsMI	73
FortWayneIN	52
IndianapolisIN	125
ChicagoIL	475
MilwaukeeWI	125
GreenBayWI	52
MinneapolisMN	227
DesMoinesIA	74
KansasCityMO	109
StLouisMO	147
LittleRockAR	43
JacksonMS	36
NewOrleansLA	129
HoustonTX	278
AustinTX	65
DallasTX	335
SanAntonioTX	70
ElPasoTX	55
OklahomaCityOK	74
TulsaOK	66
WichitaKS	38
OmahaNE	76
BillingsMT	36
DenverCO	235
AlbuquerqueNM	48
PhoenixAZ	195

THAILAND	
LasVegasNV	117
SaltLakeCityUT	104
BoiseCityID	91
SeattleWA	257
PortlandOR	177
SanJoseCA	587
SacramentoCA	115
FresnoCA	49
LosAngelesCA	871
SanDiegoCA	157
TURKEY	
BostonMA	150
NewYorkNY	488
PittsburghPA	40
PhiladelphiaPA	117
BaltimoreMD	172
AtlantaGA	91
OrlandoFL	38
MiamiFL	65
TampaFL	43
BirminghamAL	37
ClevelandOH	54
DetroitMI	91
IndianapolisIN	43
ChicagoIL	153
MilwaukeeWI	38
MinneapolisMN	66
StLouisMO	47
NewOrleansLA	41
HoustonTX	84
DallasTX	95
DenverCO	55
PhoenixAZ	41
SeattleWA	43
SanJoseCA	99
LosAngelesCA	163
UNITED KINGDOM	
BostonMA	264
AlbanyNY	41
SyracuseNY	34
BuffaloNY	34
NewYorkNY	846
PittsburghPA	65
HarrisburgPA	40
PhiladelphiaPA	201
BaltimoreMD	289
CharlestonWV	34
RichmondVA	36
NorfolkVA	40
RaleighNC	52
CharlotteNC	47
GreenvilleSC	34
AtlantaGA	144
JacksonvilleFL	52
OrlandoFL	59
MiamiFL	102
TampaFL	66
BirminghamAL	58
NashvilleTN	45
MemphisTN	41
LouisvilleKY	38
ClevelandOH	87
ColumbusOH	47
CincinnatiOH	43
DetroitMI	144
GrandRapidsMI	40

UNITED KINGDOM	
IndianapolisIN	66
ChicagoIL	236
MilwaukeeWI	60
MinneapolisMN	100
DesMoinesIA	34
KansasCityMO	48
StLouisMO	71
NewOrleansLA	63
HoustonTX	124
DallasTX	139
DenverCO	80
PhoenixAZ	58
SeattleWA	58
PortlandOR	40
SanJoseCA	133
LosAngelesCA	220
SanDiegoCA	40
VENEZUELA	
BostonMA	47
NewYorkNY	173
PhiladelphiaPA	44
BaltimoreMD	65
AtlantaGA	48
MiamiFL	41
ChicagoIL	51
HoustonTX	38
DallasTX	40
LosAngelesCA	48
VIETNAM	
BostonMA	137
NewYorkNY	467
PittsburghPA	43
PhiladelphiaPA	115
BaltimoreMD	176
AtlantaGA	104
JacksonvilleFL	37
OrlandoFL	44
MiamiFL	73
TampaFL	49
BirminghamAL	44
NashvilleTN	37
MemphisTN	36
ClevelandOH	60
ColumbusOH	34
DetroitMI	107
IndianapolisIN	52
ChicagoIL	198
MilwaukeeWI	52
MinneapolisMN	95
KansasCityMO	45
StLouisMO	60
NewOrleansLA	54
HoustonTX	117
DallasTX	140
DenverCO	99
PhoenixAZ	82
LasVegasNV	49
SaltLakeCityUT	44
BoiseCityID	38
SeattleWA	110
PortlandOR	76
SanJoseCA	249
SacramentoCA	49
LosAngelesCA	368
SanDiegoCA	67

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APPENDIX B: ESTIMATED ORIGIN DESTINATION TABLE FOR U.S. EXPORTS

Albany, NY	
BELGIUM	54
BRAZIL	85
CHINAMNLND	977
CHINATAIWAN	77
FRANCE	37
GERMANY	107
HONGKONG	110
INDIA	58
INDONESIA	43
ITALY	92
JAPAN	104
MALAYSIA	44
NETHERLANDS	51
SOUTHKOREA	70
SPAIN	36
THAILAND	59
UNITEDKINGDOM	49
Albuquerque, NM	
BRAZIL	43
CHINAMNLND	890
CHINATAIWAN	70
GERMANY	41
HONGKONG	99
INDONESIA	37
ITALY	40
JAPAN	99
MALAYSIA	34
SOUTHKOREA	65
THAILAND	51
Atlanta, GA	
ARGENTINA	51
AUSTRALIA	106
BANGLADESH	51
BELGIUM	188
BRAZIL	409
CHILE	136
CHINAMNLND	4517
CHINATAIWAN	354
COLOMBIA	107
COSTARICA	190
DOMINICANREP	137
ECUADOR	88
ELSALVADOR	45
FRANCE	129
GERMANY	371
GUATEMALA	122
HONDURAS	133
HONGKONG	507
INDIA	229
INDONESIA	196
ISRAEL	65
ITALY	341
JAPAN	485
MALAYSIA	185
NETHERLANDS	181
NEWZEALAND	45
PAKISTAN	80
PERU	36
PHILIPPINES	95
Atlanta, GA	
RUSSIA	44
SINGAPORE	66
SOUTHAFRICA	48
SOUTHKOREA	323
SPAIN	125
SWEDEN	52
THAILAND	271
TURKEY	92
UNITEDKINGDOM	173
VENEZUELA	118
VIETNAM	150
Austin, TX	
BELGIUM	37
BRAZIL	80
CHINAMNLND	1182
CHINATAIWAN	92
GERMANY	73
HONGKONG	132
INDIA	51
INDONESIA	51
ITALY	70
JAPAN	128
MALAYSIA	48
NETHERLANDS	36
SOUTHKOREA	85
THAILAND	70
VIETNAM	38
Baltimore, MD	
ARGENTINA	87
AUSTRALIA	165
AUSTRIA	56
BANGLADESH	92
BELGIUM	372
BRAZIL	655
CHILE	185
CHINAMNLND	7614
CHINATAIWAN	598
COLOMBIA	137
COSTARICA	217
DENMARK	59
DOMINICANREP	191
ECUADOR	111
ELSALVADOR	58
FINLAND	47
FRANCE	257
GERMANY	728
GUATEMALA	154
HONDURAS	168
HONGKONG	859
INDIA	422
INDONESIA	330
ISRAEL	122
ITALY	654
JAPAN	813
MALAYSIA	321
NETHERLANDS	360
NEWZEALAND	71
PAKISTAN	147
PERU	48
Baltimore, MD	
PHILIPPINES	158
POLAND	60
PORTUGAL	45
RUSSIA	87
SINGAPORE	113
SOUTHAFRICA	82
SOUTHKOREA	545
SPAIN	250
SRILANKA	55
SWEDEN	103
THAILAND	459
TURKEY	174
UNITEDKINGDOM	346
VENEZUELA	157
VIETNAM	253
Billings, MT	
CHINAMNLND	691
CHINATAIWAN	55
HONGKONG	76
JAPAN	80
SOUTHKOREA	51
THAILAND	38
Birmingham, AL	
AUSTRALIA	45
BELGIUM	76
BRAZIL	173
CHILE	59
CHINAMNLND	1934
CHINATAIWAN	153
COLOMBIA	45
COSTARICA	77
DOMINICANREP	58
ECUADOR	40
FRANCE	52
GERMANY	148
GUATEMALA	54
HONDURAS	59
HONGKONG	217
INDIA	95
INDONESIA	84
ITALY	137
JAPAN	209
MALAYSIA	80
NETHERLANDS	73
PHILIPPINES	41
SOUTHKOREA	139
SPAIN	49
THAILAND	115
TURKEY	37
UNITEDKINGDOM	69
VENEZUELA	49
VIETNAM	63
Boise City, ID	
AUSTRALIA	34
BRAZIL	51
CHINAMNLND	1827
CHINATAIWAN	143
GERMANY	58
HONGKONG	198
Boise City, ID	
INDIA	58
INDONESIA	70
ITALY	55
JAPAN	214
MALAYSIA	66
PHILIPPINES	36
SOUTHKOREA	136
THAILAND	98
VIETNAM	55
Boston, MA	
ARGENTINA	70
AUSTRALIA	128
AUSTRIA	52
BANGLADESH	77
BELGIUM	337
BRAZIL	529
CHILE	135
CHINAMNLND	5918
CHINATAIWAN	464
COLOMBIA	95
COSTARICA	143
DENMARK	55
DOMINICANREP	133
ECUADOR	78
ELSALVADOR	40
FINLAND	43
FRANCE	234
GERMANY	675
GUATEMALA	109
HONDURAS	118
HONGKONG	669
INDIA	356
INDONESIA	260
ISRAEL	104
ITALY	580
JAPAN	629
MALAYSIA	271
NETHERLANDS	324
NEWZEALAND	55
PAKISTAN	125
PERU	34
PHILIPPINES	124
POLAND	55
PORTUGAL	41
RUSSIA	80
SINGAPORE	89
SOUTHAFRICA	69
SOUTHKOREA	423
SPAIN	229
SRILANKA	45
SWEDEN	96
THAILAND	360
TURKEY	153
UNITEDKINGDOM	316
VENEZUELA	113
VIETNAM	198
Buffalo, NY	
BELGIUM	45
BRAZIL	74
Buffalo, NY	
CHINAMNLND	971
CHINATAIWAN	77
GERMANY	89
HONGKONG	110
INDIA	52
INDONESIA	43
ITALY	80
JAPAN	104
MALAYSIA	40
NETHERLANDS	44
SOUTHKOREA	70
THAILAND	59
UNITEDKINGDOM	41
Charleston, SC	
CHINAMNLND	319
HONGKONG	36
JAPAN	34
Charleston, WV	
BELGIUM	44
BRAZIL	81
CHINAMNLND	964
CHINATAIWAN	76
GERMANY	88
HONGKONG	109
INDIA	52
INDONESIA	41
ITALY	80
JAPAN	103
MALAYSIA	40
NETHERLANDS	43
SOUTHKOREA	69
THAILAND	58
UNITEDKINGDOM	41
Charlotte, NC	
BELGIUM	60
BRAZIL	118
CHILE	37
CHINAMNLND	1308
CHINATAIWAN	103
COSTARICA	49
DOMINICANREP	38
FRANCE	41
GERMANY	117
HONDURAS	34
HONGKONG	147
INDIA	71
INDONESIA	58
ITALY	107
JAPAN	139
MALAYSIA	55
NETHERLANDS	58
SOUTHKOREA	93
SPAIN	40
THAILAND	80
UNITEDKINGDOM	55
VIETNAM	44
Chattanooga, TN	
CHINAMNLND	381
HONGKONG	43

Chattanooga, TN	
JAPAN	41

Chicago, IL	
ARGENTINA	77
AUSTRALIA	188
AUSTRIA	48
BANGLADESH	88
BELGIUM	312
BRAZIL	533
CHILE	203
CHINAMNLND	8742
CHINATAIWAN	687
COLOMBIA	109
COSTARICA	159
DENMARK	51
DOMINICANREP	135
ECUADOR	124
ELSALVADOR	65
FINLAND	41
FRANCE	214
GERMANY	624
GUATEMALA	172
HONDURAS	188
HONGKONG	974
INDIA	396
INDONESIA	368
ISRAEL	109
ITALY	565
JAPAN	949
MALAYSIA	352
NETHERLANDS	301
NEWZEALAND	82
PAKISTAN	139
PERU	52
PHILIPPINES	180
POLAND	52
PORTUGAL	37
RUSSIA	76
SINGAPORE	126
SOUTHAFRICA	74
SOUTHKOREA	628
SPAIN	206
SRILANKA	51
SWEDEN	89
THAILAND	514
TURKEY	155
UNITEDKINGDOM	283
VENEZUELA	124
VIETNAM	284

Cincinnati, OH	
BELGIUM	56
BRAZIL	103
CHILE	36
CHINAMNLND	1410
CHINATAIWAN	111
COSTARICA	34
FRANCE	38
GERMANY	111
HONGKONG	158
INDIA	70
INDONESIA	60
ITALY	102
JAPAN	151
MALAYSIA	58
NETHERLANDS	54

Cincinnati, OH	
SOUTHKOREA	102
SPAIN	37
THAILAND	84
UNITEDKINGDOM	51
VIETNAM	47

Cleveland, OH	
AUSTRALIA	56
BELGIUM	113
BRAZIL	190
CHILE	63
CHINAMNLND	2630
CHINATAIWAN	206
COLOMBIA	37
COSTARICA	55
DOMINICANREP	49
ECUADOR	37
FRANCE	78
GERMANY	220
GUATEMALA	52
HONDURAS	56
HONGKONG	295
INDIA	135
INDONESIA	113
ISRAEL	38
ITALY	202
JAPAN	283
MALAYSIA	107
NETHERLANDS	110
PAKISTAN	47
PHILIPPINES	55
SINGAPORE	38
SOUTHKOREA	188
SPAIN	76
THAILAND	157
TURKEY	55
UNITEDKINGDOM	103
VENEZUELA	41
VIETNAM	87

Columbia, SC	
BELGIUM	34
BRAZIL	71
CHINAMNLND	749
CHINATAIWAN	59
GERMANY	66
HONGKONG	84
INDIA	40
ITALY	60
JAPAN	80
SOUTHKOREA	54
THAILAND	45

Columbus, OH	
BELGIUM	60
BRAZIL	102
CHILE	36
CHINAMNLND	1465
CHINATAIWAN	115
FRANCE	41
GERMANY	120
HONGKONG	165
INDIA	73
INDONESIA	63
ITALY	109
JAPAN	158
MALAYSIA	60

Columbus, OH	
NETHERLANDS	58
SOUTHKOREA	106
SPAIN	40
THAILAND	88
UNITEDKINGDOM	55
VIETNAM	48

Corpus Christi, TX	
BRAZIL	38
CHINAMNLND	566
CHINATAIWAN	44
GERMANY	36
HONGKONG	63
JAPAN	62
SOUTHKOREA	41

Dallas, TX	
ARGENTINA	55
AUSTRALIA	144
BANGLADESH	62
BELGIUM	184
BRAZIL	401
CHILE	159
CHINAMNLND	6192
CHINATAIWAN	486
COLOMBIA	92
COSTARICA	131
DOMINICANREP	107
ECUADOR	102
ELSALVADOR	52
FRANCE	126
GERMANY	367
GUATEMALA	140
HONDURAS	153
HONGKONG	691
INDIA	256
INDONESIA	265
ISRAEL	69
ITALY	349
JAPAN	676
MALAYSIA	249
NETHERLANDS	179
NEWZEALAND	63
PAKISTAN	89
PERU	43
PHILIPPINES	129
RUSSIA	45
SINGAPORE	89
SOUTHAFRICA	54
SOUTHKOREA	448
SPAIN	121
SWEDEN	52
THAILAND	363
TURKEY	98
UNITEDKINGDOM	168
VENEZUELA	98
VIETNAM	201

Dayton, OH	
BRAZIL	45
CHINAMNLND	646
CHINATAIWAN	51
GERMANY	52
HONGKONG	73
ITALY	47
JAPAN	70
SOUTHKOREA	47

Dayton, OH	
THAILAND	38

Denver, CO	
AUSTRALIA	92
BANGLADESH	43
BELGIUM	106
BRAZIL	203
CHILE	82
CHINAMNLND	4480
CHINATAIWAN	352
COLOMBIA	40
COSTARICA	52
DOMINICANREP	47
ECUADOR	49
FRANCE	73
GERMANY	213
GUATEMALA	73
HONDURAS	80
HONGKONG	495
INDIA	154
INDONESIA	183
ISRAEL	40
ITALY	199
JAPAN	501
MALAYSIA	173
NETHERLANDS	103
NEWZEALAND	40
PAKISTAN	54
PHILIPPINES	91
SINGAPORE	62
SOUTHKOREA	328
SPAIN	67
THAILAND	254
TURKEY	56
UNITEDKINGDOM	95
VENEZUELA	44
VIETNAM	142

Des Moines, IA	
BELGIUM	45
BRAZIL	76
CHINAMNLND	1377
CHINATAIWAN	109
GERMANY	89
HONGKONG	154
INDIA	58
INDONESIA	58
ITALY	81
JAPAN	151
MALAYSIA	55
NETHERLANDS	43
SOUTHKOREA	99
THAILAND	80
UNITEDKINGDOM	40
VIETNAM	44

Detroit, MI	
ARGENTINA	44
AUSTRALIA	99
BANGLADESH	51
BELGIUM	188
BRAZIL	304
CHILE	106
CHINAMNLND	4638
CHINATAIWAN	364
COLOMBIA	59
COSTARICA	87

Detroit, MI	
DOMINICANREP	73
ECUADOR	63
FRANCE	131
GERMANY	375
GUATEMALA	88
HONDURAS	96
HONGKONG	521
INDIA	229
INDONESIA	198
ISRAEL	65
ITALY	339
JAPAN	500
MALAYSIA	190
NETHERLANDS	183
NEWZEALAND	43
PAKISTAN	80
PHILIPPINES	96
RUSSIA	45
SINGAPORE	67
SOUTHAFRICA	43
SOUTHKOREA	332
SPAIN	125
SWEDEN	54
THAILAND	276
TURKEY	92
UNITEDKINGDOM	173
VENEZUELA	67
VIETNAM	153

Duluth, MN	
CHINAMNLND	194

El Paso, TX	
BRAZIL	56
CHINAMNLND	1046
CHINATAIWAN	82
GERMANY	52
HONGKONG	115
INDIA	38
INDONESIA	44
ITALY	51
JAPAN	117
MALAYSIA	41
SOUTHKOREA	76
THAILAND	60

Fargo, ND	
CHINAMNLND	573
CHINATAIWAN	45
HONGKONG	63
JAPAN	65
SOUTHKOREA	43

Fort Wayne, IN	
BELGIUM	37
BRAZIL	63
CHINAMNLND	962
CHINATAIWAN	76
GERMANY	74
HONGKONG	109
INDIA	45
INDONESIA	41
ITALY	67
JAPAN	104
MALAYSIA	38
NETHERLANDS	36
SOUTHKOREA	69
THAILAND	58

Fort Wayne, IN	
UNITEDKINGDOM	34

Fresno, CA	
CHINAMNLND	967
CHINATAIWAN	76
HONGKONG	106
INDONESIA	38
JAPAN	111
MALAYSIA	36
SOUTHKOREA	71
THAILAND	54

Grand Rapids, MI	
BELGIUM	54
BRAZIL	85
CHINAMNLND	1338
CHINATAIWAN	104
FRANCE	37
GERMANY	104
HONGKONG	150
INDIA	65
INDONESIA	58
ITALY	95
JAPAN	144
MALAYSIA	55
NETHERLANDS	51
SOUTHKOREA	96
SPAIN	34
THAILAND	80
UNITEDKINGDOM	48
VIETNAM	44

Green Bay, WI	
BRAZIL	55
CHINAMNLND	969
CHINATAIWAN	76
GERMANY	65
HONGKONG	109
INDIA	41
INDONESIA	41
ITALY	59
JAPAN	106
MALAYSIA	38
SOUTHKOREA	70
THAILAND	56

Greensboro, NC	
BELGIUM	41
BRAZIL	77
CHINAMNLND	875
CHINATAIWAN	69
GERMANY	80
HONGKONG	99
INDIA	49
INDONESIA	38
ITALY	73
JAPAN	93
MALAYSIA	37
NETHERLANDS	40
SOUTHKOREA	63
THAILAND	54
UNITEDKINGDOM	37

Greenville, NC	
CHINAMNLND	364
GERMANY	34
HONGKONG	41
JAPAN	38
BELGIUM	45
BRAZIL	92

Greenville, NC	
CHINAMNLND	1024
CHINATAIWAN	80
COSTARICA	38
GERMANY	88
HONGKONG	115
INDIA	55
INDONESIA	45
ITALY	81
JAPAN	109
MALAYSIA	43
NETHERLANDS	44
SOUTHKOREA	73
THAILAND	62
UNITEDKINGDOM	41
VIETNAM	34

Harrisburg, PA	
BELGIUM	51
BRAZIL	87
CHINAMNLND	1025
CHINATAIWAN	81
FRANCE	36
GERMANY	99
HONGKONG	115
INDIA	58
INDONESIA	44
ITALY	89
JAPAN	110
MALAYSIA	44
NETHERLANDS	49
SOUTHKOREA	73
SPAIN	34
THAILAND	62
UNITEDKINGDOM	47
VIETNAM	34

Houston, TX	
ARGENTINA	48
AUSTRALIA	120
BANGLADESH	51
BELGIUM	163
BRAZIL	364
CHILE	144
CHINAMNLND	5107
CHINATAIWAN	401
COLOMBIA	91
COSTARICA	132
DOMINICANREP	104
ECUADOR	95
ELSALVADOR	49
FRANCE	113
GERMANY	326
GUATEMALA	132
HONDURAS	144
HONGKONG	570
INDIA	221
INDONESIA	220
ISRAEL	60
ITALY	308
JAPAN	556
MALAYSIA	205
NETHERLANDS	159
NEWZEALAND	52
PAKISTAN	77
PERU	38
PHILIPPINES	106
RUSSIA	40

Houston, TX	
SINGAPORE	74
SOUTHAFRICA	47
SOUTHKOREA	367
SPAIN	107
SWEDEN	47
THAILAND	301
TURKEY	85
UNITEDKINGDOM	148
VENEZUELA	95
VIETNAM	166

Indianapolis, IN	
AUSTRALIA	51
BELGIUM	87
BRAZIL	154
CHILE	58
CHINAMNLND	2285
CHINATAIWAN	180
COSTARICA	48
DOMINICANREP	40
ECUADOR	36
FRANCE	60
GERMANY	173
GUATEMALA	49
HONDURAS	54
HONGKONG	257
INDIA	109
INDONESIA	98
ITALY	158
JAPAN	247
MALAYSIA	93
NETHERLANDS	84
PAKISTAN	38
PHILIPPINES	47
SOUTHKOREA	165
SPAIN	58
THAILAND	136
TURKEY	43
UNITEDKINGDOM	80
VENEZUELA	37
VIETNAM	76

Jackson, MS	
BRAZIL	51
CHINAMNLND	647
CHINATAIWAN	51
GERMANY	45
HONGKONG	73
ITALY	43
JAPAN	70
SOUTHKOREA	47
THAILAND	38

Jacksonville, FL	
AUSTRALIA	37
BELGIUM	67
BRAZIL	163
CHILE	48
CHINAMNLND	1607
CHINATAIWAN	126
COLOMBIA	49
COSTARICA	93
DOMINICANREP	65
FRANCE	47
GERMANY	133
GUATEMALA	44
HONDURAS	48
HONGKONG	180

Jacksonville, FL	
INDIA	82
INDONESIA	70
ITALY	122
JAPAN	173
MALAYSIA	66
NETHERLANDS	66
PHILIPPINES	34
SOUTHKOREA	115
SPAIN	45
THAILAND	96
UNITEDKINGDOM	62
VENEZUELA	54
VIETNAM	54

Kansas City, MO	
AUSTRALIA	45
BELGIUM	63
BRAZIL	117
CHILE	45
CHINAMNLND	2018
CHINATAIWAN	158
COSTARICA	34
FRANCE	44
GERMANY	128
GUATEMALA	38
HONDURAS	41
HONGKONG	225
INDIA	85
INDONESIA	85
ITALY	117
JAPAN	220
MALAYSIA	81
NETHERLANDS	62
PHILIPPINES	41
SOUTHKOREA	146
SPAIN	41
THAILAND	118
UNITEDKINGDOM	58
VIETNAM	66

Knoxville, TN	
BRAZIL	62
CHINAMNLND	725
CHINATAIWAN	56
GERMANY	63
HONGKONG	82
INDIA	38
ITALY	58
JAPAN	77
SOUTHKOREA	52
THAILAND	44

Las Vegas, NV	
AUSTRALIA	49
BELGIUM	40
BRAZIL	71
CHILE	36
CHINAMNLND	2282
CHINATAIWAN	179
GERMANY	80
GUATEMALA	47
HONDURAS	51
HONGKONG	249
INDIA	76
INDONESIA	92
ITALY	76
JAPAN	261
MALAYSIA	85

Las Vegas, NV	
NETHERLANDS	38
PHILIPPINES	47
SOUTHKOREA	168
THAILAND	126
UNITEDKINGDOM	36
VIETNAM	70

Lexington, KY	
BRAZIL	54
CHINAMNLND	719
CHINATAIWAN	56
GERMANY	55
HONGKONG	81
INDIA	36
ITALY	51
JAPAN	77
SOUTHKOREA	52
THAILAND	43

Little Rock, AR	
BRAZIL	54
CHINAMNLND	774
CHINATAIWAN	60
GERMANY	51
HONGKONG	87
INDIA	34
ITALY	48
JAPAN	84
SOUTHKOREA	55
THAILAND	47

Los Angeles, CA	
ARGENTINA	103
AUSTRALIA	383
AUSTRIA	47
BANGLADESH	155
BELGIUM	297
BRAZIL	585
CHILE	298
CHINAMNLND	16903
CHINATAIWAN	1327
COLOMBIA	107
COSTARICA	135
DENMARK	49
DOMINICANREP	121
ECUADOR	176
ELSALVADOR	146
FINLAND	41
FRANCE	202
GERMANY	599
GUATEMALA	412
HONDURAS	449
HONGKONG	1848
INDIA	562
INDONESIA	684
ISRAEL	118
ITALY	578
JAPAN	1929
MALAYSIA	639
NETHERLANDS	289
NEWZEALAND	173
PAKISTAN	166
PERU	77
PHILIPPINES	343
POLAND	51
PORTUGAL	34
RUSSIA	76
SINGAPORE	231

Los Angeles, CA	
SOUTHAFRICA	95
SOUTHKOREA	1248
SPAIN	190
SRILANKA	78
SWEDEN	85
THAILAND	941
TURKEY	166
UNITEDKINGDOM	264
VENEZUELA	117
VIETNAM	528

Louisville, KY	
BELGIUM	49
BRAZIL	96
CHILE	34
CHINAMNLND	1311
CHINATAIWAN	103
FRANCE	34
GERMANY	99
HONGKONG	147
INDIA	63
INDONESIA	56
ITALY	91
JAPAN	142
MALAYSIA	54
NETHERLANDS	48
SOUTHKOREA	95
THAILAND	78
UNITEDKINGDOM	45
VIETNAM	43

Memphis, TN	
AUSTRALIA	36
BELGIUM	55
BRAZIL	118
CHILE	45
CHINAMNLND	1544
CHINATAIWAN	121
COSTARICA	43
DOMINICANREP	34
FRANCE	38
GERMANY	109
GUATEMALA	41
HONDURAS	44
HONGKONG	173
INDIA	73
INDONESIA	67
ITALY	102
JAPAN	166
MALAYSIA	63
NETHERLANDS	54
SOUTHKOREA	111
SPAIN	36
THAILAND	92
UNITEDKINGDOM	49
VIETNAM	51

Miami, FL	
ARGENTINA	38
AUSTRALIA	73
BANGLADESH	36
BELGIUM	133
BRAZIL	317
CHILE	98
CHINAMNLND	3094
CHINATAIWAN	243
COLOMBIA	89

Miami, FL	
COSTARICA	166
DOMINICANREP	120
ECUADOR	63
FRANCE	92
GERMANY	261
GUATEMALA	87
HONDURAS	95
HONGKONG	350
INDIA	165
INDONESIA	137
ISRAEL	47
ITALY	242
JAPAN	330
MALAYSIA	129
NETHERLANDS	128
PAKISTAN	58
PHILIPPINES	66
SINGAPORE	45
SOUTHAFRICA	36
SOUTHKOREA	221
SPAIN	89
SWEDEN	37
THAILAND	188
TURKEY	66
UNITEDKINGDOM	121
VENEZUELA	100
VIETNAM	103

Milwaukee, WI	
AUSTRALIA	47
BELGIUM	78
BRAZIL	135
CHILE	51
CHINAMNLND	2305
CHINATAIWAN	181
COSTARICA	38
FRANCE	54
GERMANY	158
GUATEMALA	43
HONDURAS	47
HONGKONG	257
INDIA	102
INDONESIA	96
ITALY	144
JAPAN	251
MALAYSIA	92
NETHERLANDS	77
PAKISTAN	36
PHILIPPINES	47
SOUTHKOREA	166
SPAIN	52
THAILAND	135
TURKEY	40
UNITEDKINGDOM	71
VIETNAM	74

Minneapolis MN	
AUSTRALIA	87
BANGLADESH	41
BELGIUM	132
BRAZIL	223
CHILE	84
CHINAMNLND	4226
CHINATAIWAN	331
COLOMBIA	43
COSTARICA	62

Minneapolis MN	
DOMINICANREP	52
ECUADOR	49
FRANCE	91
GERMANY	262
GUATEMALA	69
HONDURAS	76
HONGKONG	470
INDIA	172
INDONESIA	176
ISRAEL	47
ITALY	242
JAPAN	464
MALAYSIA	168
NETHERLANDS	128
NEWZEALAND	36
PAKISTAN	60
PHILIPPINES	87
SINGAPORE	60
SOUTHKOREA	306
SPAIN	87
SWEDEN	37
THAILAND	245
TURKEY	67
UNITEDKINGDOM	120
VENEZUELA	49
VIETNAM	136

Mobile, AL	
BRAZIL	73
CHINAMNLND	872
CHINATAIWAN	69
GERMANY	62
HONGKONG	98
INDIA	41
INDONESIA	37
ITALY	59
JAPAN	95
MALAYSIA	36
SOUTHKOREA	63
THAILAND	52

Nashville, TN	
AUSTRALIA	37
BELGIUM	60
BRAZIL	126
CHILE	45
CHINAMNLND	1634
CHINATAIWAN	128
COSTARICA	45
DOMINICANREP	36
FRANCE	41
GERMANY	120
GUATEMALA	40
HONDURAS	44
HONGKONG	184
INDIA	78
INDONESIA	70
ITALY	110
JAPAN	176
MALAYSIA	67
NETHERLANDS	59
PHILIPPINES	34
SOUTHKOREA	118
SPAIN	40
THAILAND	98
UNITEDKINGDOM	55

Nashville, TN	
VIETNAM	54

New Orleans, LA	
AUSTRALIA	55
BELGIUM	82
BRAZIL	188
CHILE	74
CHINAMNLND	2371
CHINATAIWAN	187
COLOMBIA	49
COSTARICA	78
DOMINICANREP	59
ECUADOR	51
FRANCE	56
GERMANY	163
GUATEMALA	69
HONDURAS	76
HONGKONG	265
INDIA	107
INDONESIA	102
ITALY	154
JAPAN	257
MALAYSIA	96
NETHERLANDS	80
PAKISTAN	37
PHILIPPINES	49
SINGAPORE	34
SOUTHKOREA	170
SPAIN	55
THAILAND	140
TURKEY	43
UNITEDKINGDOM	76
VENEZUELA	52
VIETNAM	77

New York, NY	
ARGENTINA	235
AUSTRALIA	434
AUSTRIA	168
BANGLADESH	251
BELGIUM	1095
BRAZIL	1826
CHILE	481
CHINAMNLND	20171
CHINATAIWAN	1584
COLOMBIA	367
COSTARICA	578
DENMARK	174
DOMINICANREP	521
ECUADOR	286
ELSALVADOR	147
FINLAND	137
FRANCE	760
GERMANY	2154
GUATEMALA	396
HONDURAS	433
HONGKONG	2277
INDIA	1166
INDONESIA	874
ISRAEL	343
ITALY	1878
JAPAN	2154
MALAYSIA	888
NETHERLANDS	1046
NEWZEALAND	187
PAKISTAN	409

New York, NY	
PERU	124
PHILIPPINES	420
POLAND	176
PORTUGAL	135
RUSSIA	253
SINGAPORE	298
SOUTHAFRICA	225
SOUTHKOREA	1447
SPAIN	749
SRILANKA	150
SWEDEN	306
THAILAND	1217
TURKEY	496
UNITEDKINGDOM	1017
VENEZUELA	423
VIETNAM	669

Norfolk, VA	
BELGIUM	51
BRAZIL	93
CHINAMNLND	1002
CHINATAIWAN	78
FRANCE	36
GERMANY	99
HONGKONG	113
INDIA	58
INDONESIA	44
ITALY	89
JAPAN	107
MALAYSIA	44
NETHERLANDS	49
SOUTHKOREA	71
SPAIN	34
THAILAND	60
UNITEDKINGDOM	47

Oklahoma City, OK	
BELGIUM	38
BRAZIL	78
CHINAMNLND	1381
CHINATAIWAN	109
GERMANY	77
HONGKONG	154
INDIA	54
INDONESIA	59
ITALY	71
JAPAN	151
MALAYSIA	55
NETHERLANDS	37
SOUTHKOREA	99
THAILAND	81
UNITEDKINGDOM	34
VIETNAM	44

Omaha, NE	
BELGIUM	41
BRAZIL	71
CHINAMNLND	1417
CHINATAIWAN	111
GERMANY	81
HONGKONG	157
INDIA	55
INDONESIA	59
ITALY	76
JAPAN	157
MALAYSIA	56
NETHERLANDS	40

Omaha, NE	
SOUTHKOREA	103
THAILAND	81
UNITEDKINGDOM	37
VIETNAM	45
Orlando, FL	
AUSTRALIA	44
BELGIUM	78
BRAZIL	184
CHILE	59
CHINAMNLND	1882
CHINATAIWAN	148
COLOMBIA	51
COSTARICA	93
DOMINICANREP	66
ECUADOR	38
FRANCE	54
GERMANY	154
GUATEMALA	54
HONDURAS	58
HONGKONG	212
INDIA	98
INDONESIA	82
ITALY	143
JAPAN	202
MALAYSIA	78
NETHERLANDS	76
PAKISTAN	34
PHILIPPINES	40
SOUTHKOREA	135
SPAIN	52
THAILAND	114
TURKEY	38
UNITEDKINGDOM	71
VENEZUELA	58
VIETNAM	62
Philadelphia, PA	
ARGENTINA	58
AUSTRALIA	109
AUSTRIA	40
BANGLADESH	60
BELGIUM	257
BRAZIL	448
CHILE	122
CHINAMNLND	5012
CHINATAIWAN	393
COLOMBIA	95
COSTARICA	153
DENMARK	41
DOMINICANREP	133
ECUADOR	74
ELSALVADOR	38
FRANCE	179
GERMANY	503
GUATEMALA	102
HONDURAS	111
HONGKONG	565
INDIA	283
INDONESIA	217
ISRAEL	82
ITALY	449
JAPAN	537
MALAYSIA	214
NETHERLANDS	249
NEWZEALAND	47

Philadelphia, PA	
PAKISTAN	99
PHILIPPINES	104
POLAND	41
RUSSIA	59
SINGAPORE	74
SOUTHAFRICA	55
SOUTHKOREA	360
SPAIN	174
SRILANKA	36
SWEDEN	71
THAILAND	302
TURKEY	120
UNITEDKINGDOM	240
VENEZUELA	109
VIETNAM	166
Phoenix, AZ	
AUSTRALIA	85
BANGLADESH	36
BELGIUM	77
BRAZIL	154
CHILE	65
CHINAMNLND	3745
CHINATAIWAN	294
COSTARICA	38
DOMINICANREP	34
ECUADOR	37
FRANCE	52
GERMANY	155
GUATEMALA	81
HONDURAS	89
HONGKONG	412
INDIA	128
INDONESIA	155
ITALY	148
JAPAN	420
MALAYSIA	144
NETHERLANDS	74
NEWZEALAND	38
PAKISTAN	41
PHILIPPINES	77
SINGAPORE	52
SOUTHKOREA	273
SPAIN	49
THAILAND	212
TURKEY	43
UNITEDKINGDOM	69
VIETNAM	118
Pittsburgh, PA	
AUSTRALIA	40
BELGIUM	84
BRAZIL	146
CHILE	44
CHINAMNLND	1849
CHINATAIWAN	146
COSTARICA	44
DOMINICANREP	38
FRANCE	58
GERMANY	163
GUATEMALA	36
HONDURAS	40
HONGKONG	209
INDIA	98
INDONESIA	80
ITALY	148

Pittsburgh, PA	
JAPAN	198
MALAYSIA	76
NETHERLANDS	81
PAKISTAN	34
PHILIPPINES	38
SOUTHKOREA	133
SPAIN	56
THAILAND	111
TURKEY	40
UNITEDKINGDOM	77
VIETNAM	62
Portland, ME	
BELGIUM	38
BRAZIL	58
CHINAMNLND	650
CHINATAIWAN	51
GERMANY	76
HONGKONG	74
INDIA	40
ITALY	65
JAPAN	69
NETHERLANDS	37
SOUTHKOREA	47
THAILAND	40
UNITEDKINGDOM	36
Portland, OR	
AUSTRALIA	69
BELGIUM	54
BRAZIL	91
CHILE	44
CHINAMNLND	3615
CHINATAIWAN	284
FRANCE	37
GERMANY	109
GUATEMALA	52
HONDURAS	56
HONGKONG	389
INDIA	113
INDONESIA	137
ITALY	104
JAPAN	427
MALAYSIA	129
NETHERLANDS	52
PHILIPPINES	71
SINGAPORE	47
SOUTHKOREA	269
SPAIN	34
THAILAND	191
UNITEDKINGDOM	48
VIETNAM	109
Raleigh, NC	
BELGIUM	69
BRAZIL	128
CHILE	38
CHINAMNLND	1399
CHINATAIWAN	110
COSTARICA	49
DOMINICANREP	41
FRANCE	47
GERMANY	133
HONDURAS	36
HONGKONG	158
INDIA	78
INDONESIA	62

Raleigh, NC	
ITALY	121
JAPAN	148
MALAYSIA	60
NETHERLANDS	66
SOUTHKOREA	100
SPAIN	45
THAILAND	85
UNITEDKINGDOM	63
VIETNAM	47
ReddingCA	
CHINAMNLND	214
Richmond, VA	
BELGIUM	45
BRAZIL	84
CHINAMNLND	929
CHINATAIWAN	73
GERMANY	89
HONGKONG	104
INDIA	52
INDONESIA	40
ITALY	81
JAPAN	99
MALAYSIA	40
NETHERLANDS	44
SOUTHKOREA	66
THAILAND	56
UNITEDKINGDOM	43
Rochester, NY	
BELGIUM	38
BRAZIL	63
CHINAMNLND	782
CHINATAIWAN	62
GERMANY	76
HONGKONG	88
INDIA	44
INDONESIA	34
ITALY	67
JAPAN	84
NETHERLANDS	37
SOUTHKOREA	56
THAILAND	47
UNITEDKINGDOM	36
Sacramento, CA	
AUSTRALIA	49
BELGIUM	36
BRAZIL	67
CHILE	34
CHINAMNLND	2289
CHINATAIWAN	180
GERMANY	73
GUATEMALA	44
HONDURAS	48
HONGKONG	249
INDIA	74
INDONESIA	91
ITALY	69
JAPAN	265
MALAYSIA	85
NETHERLANDS	34
PHILIPPINES	45
SOUTHKOREA	170
THAILAND	125
VIETNAM	70

Salt Lake City, UT	
AUSTRALIA	41
BELGIUM	37
BRAZIL	69
CHINAMNLND	2036
CHINATAIWAN	159
GERMANY	76
GUATEMALA	36
HONDURAS	40
HONGKONG	223
INDIA	67
INDONESIA	81
ITALY	71
JAPAN	232
MALAYSIA	77
NETHERLANDS	36
PHILIPPINES	41
SOUTHKOREA	150
THAILAND	113
VIETNAM	63
San Jose, CA	
ARGENTINA	63
AUSTRALIA	250
BANGLADESH	104
BELGIUM	180
BRAZIL	342
CHILE	176
CHINAMNLND	11666
CHINATAIWAN	916
COLOMBIA	62
COSTARICA	76
DOMINICANREP	69
ECUADOR	102
ELSALVADOR	81
FRANCE	124
GERMANY	365
GUATEMALA	228
HONDURAS	249
HONGKONG	1265
INDIA	378
INDONESIA	462
ISRAEL	71
ITALY	349
JAPAN	1352
MALAYSIA	431
NETHERLANDS	176
NEWZEALAND	111
PAKISTAN	111
PERU	45
PHILIPPINES	234
RUSSIA	47
SINGAPORE	155
SOUTHAFRICA	58
SOUTHKOREA	867
SPAIN	114
SRILANKA	52
SWEDEN	52
THAILAND	633
TURKEY	100
UNITEDKINGDOM	161
VENEZUELA	66
VIETNAM	357
San Antonio, TX	
BELGIUM	38
BRAZIL	84

San Antonio, TX	
CHINAMNLND	1286
CHINATAIWAN	100
GERMANY	77
HONGKONG	144
INDIA	54
INDONESIA	55
ITALY	73
JAPAN	140
MALAYSIA	52
NETHERLANDS	37
SOUTHKOREA	92
THAILAND	76
UNITEDKINGDOM	34
VIETNAM	43
San Diego, CA	
AUSTRALIA	70
BELGIUM	54
BRAZIL	107
CHILE	56
CHINAMNLND	3075
CHINATAIWAN	242
ECUADOR	34
FRANCE	37
GERMANY	109
GUATEMALA	82
HONDURAS	91
HONGKONG	335
INDIA	102
INDONESIA	124
ITALY	106
JAPAN	352
MALAYSIA	115
NETHERLANDS	52
PHILIPPINES	62
SINGAPORE	41
SOUTHKOREA	225
SPAIN	34
THAILAND	170
UNITEDKINGDOM	48
VIETNAM	96
Savannah, GA	
CHINAMNLND	337

Savannah, GA	
HONGKONG	38
JAPAN	36
Seattle, WA	
AUSTRALIA	99
BANGLADESH	45
BELGIUM	78
BRAZIL	132
CHILE	62
CHINAMNLND	5273
CHINATAIWAN	414
ECUADOR	34
FRANCE	54
GERMANY	159
GUATEMALA	71
HONDURAS	77
HONGKONG	566
INDIA	163
INDONESIA	198
ITALY	151
JAPAN	627
MALAYSIA	188
NETHERLANDS	77
NEWZEALAND	43
PAKISTAN	48
PHILIPPINES	103
SINGAPORE	69
SOUTHKOREA	393
SPAIN	49
THAILAND	278
TURKEY	43
UNITEDKINGDOM	70
VIETNAM	158
Sioux Falls, SD	
CHINAMNLND	523
CHINATAIWAN	41
HONGKONG	58
JAPAN	58
SOUTHKOREA	38
Springfield, MO	
CHINAMNLND	512
CHINATAIWAN	40
HONGKONG	58

Springfield, MO	
JAPAN	56
SOUTHKOREA	37
AUSTRALIA	59
BELGIUM	93
St. Louis, MO	
AUSTRALIA	59
BELGIUM	93
CHINAMNLND	2676
CHINATAIWAN	210
COLOMBIA	38
COSTARICA	55
DOMINICANREP	47
ECUADOR	43
FRANCE	65
GERMANY	188
GUATEMALA	59
HONDURAS	65
HONGKONG	300
INDIA	121
INDONESIA	114
ITALY	172
JAPAN	290
MALAYSIA	109
NETHERLANDS	91
PAKISTAN	43
PHILIPPINES	55
SINGAPORE	38
SOUTHKOREA	194
SPAIN	62
THAILAND	158
TURKEY	47
UNITEDKINGDOM	85
VENEZUELA	43
VIETNAM	88
Syracuse, NY	
BELGIUM	44
BRAZIL	71
CHINAMNLND	857
CHINATAIWAN	67
GERMANY	88
HONGKONG	98
INDIA	49

Syracuse, NY	
INDONESIA	37
ITALY	77
JAPAN	91
MALAYSIA	38
NETHERLANDS	43
SOUTHKOREA	62
THAILAND	52
UNITEDKINGDOM	41
Tampa, FL	
AUSTRALIA	49
BELGIUM	87
BRAZIL	205
CHILE	69
CHINAMNLND	2116
CHINATAIWAN	166
COLOMBIA	55
COSTARICA	99
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